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EFFECT OF WING HEIGHT AND DIHEDRAL ON STABILITY CHARACTERISTICS OF A 76° SWEPT WING BODY AT MACH NUMBERS FROM 1.60 TO 4.63

by Dennis E. Fuller and Maurice Feryn

Langley Research Center

Langley Station, Hampton, Va.

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SUMMARY

An investigation has been made to determine the lateral-directional and longitudinal stability characteristics of a 76° swept wing-body model having variations in wing height and geometric dihedral. The wing-body configurations include a mid, a high, and a low wing with zero geometric dihedral; the high and the low wing models also had ±5° dihedral. Tests were made at Mach numbers from 1.60 to 4.63, at angles of attack from about -4° to 20°, and at angles of sideslip from about -4° to 8°.

Results of the investigation indicate that the high wing provided a positive increment of effective dihedral and the low wing provided a negative increment of effective dihedral, each of which was essentially constant with changing Mach number. Plus and minus 5° geometric dihedral, respectively, provided positive and negative increments of effective dihedral that were approximately equivalent to the values of effective dihedral provided by the change in wing height for these configurations. The geometry of the wing pressure field was such that with increasing angle of attack, the high-wing configuration became increasingly unstable, whereas the loss in stability for the low-wing configuration became less than that for the mid-wing configuration. There were only small effects of either wing height or geometric dihedral on the longitudinal stability characteristics of the configurations.

Author

[redacted]

INTRODUCTION

There is a continuing problem of providing satisfactory lateral and directional stability for aircraft operating in the supersonic-speed range. Previous papers such as references 1 and 2 have described some of the sources of the problem and pointed out some of the factors that affect the stability characteristics at supersonic speeds.

Considerable effort has been expended to determine the effects of wing height and of geometric dihedral on static stability at the lower supersonic

*Title, Unclassified.

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Mach numbers (refs. 3 to 7). However, little information is available at the higher supersonic numbers for highly swept wings such as those now being considered in some supersonic-transport proposals. In particular, the effective dihedral for such configurations can be a troublesome parameter since the leading edges of the highly swept wings can remain subsonic and produce large values of rolling moment due to sideslip, even at relatively high supersonic speeds. Accordingly an investigation has been undertaken to determine the effects of wing height and geometric dihedral on the lateral and directional stability characteristics of a highly swept arrow wing-body configuration. Tests were also made to obtain the longitudinal characteristics of the models.

The tests were performed in the Langley Unitary Plan wind tunnel at Mach numbers from 1.6 to 4.63, at angles of attack from about -4° to 20°, and at angles of sideslip from about -4° to 8°.

SYMBOLS

The lateral force and moment data are referred to the body-axis system and the longitudinal force and moment data are referred to the stability-axis system. The reference center of moments was located at the quarter chord of the mean geometric chord or 29.20 inches aft of the nose of the body, and on the fuselage center line.

A aspect ratio

b wing span, 20.00 in.

$\bar{c}$ mean geometric chord, 13.97 in.

C_D drag coefficient, $\frac{\text{Drag}}{qS_w}$

C_L lift coefficient, $\frac{\text{Lift}}{qS_w}$

C_l rolling-moment coefficient, $\frac{\text{Rolling moment}}{qS_w b}$

C_m pitching-moment coefficient, $\frac{\text{Pitching moment}}{qS_w \bar{c}}$

$C_{l_\beta} = \frac{\Delta C_l}{\Delta \beta}$, per deg

C_n yawing-moment coefficient, $\frac{\text{Yawing moment}}{qS_wb}$

$C_{n_\beta} = \frac{\Delta C_n}{\Delta \beta}$, per deg

C_Y side-force coefficient, $\frac{\text{Side force}}{qS_w}$

$C_{Y_\beta} = \frac{\Delta C_Y}{\Delta \beta}$, per deg

L/D lift-drag ratio

S vertical distance from fuselage center line to wing chord plane

S_w reference wing area, 1.6200 sq ft

h average fuselage height at wing root

M free-stream Mach number

q free-stream dynamic pressure, lb/sq ft

R Reynolds number per foot

r radius, in.

w average fuselage width at wing root

x coordinate along X-axis, in.

α angle of attack, deg

β angle of sideslip, deg

Γ dihedral angle, deg

APPARATUS AND TESTS

Model

Drawings of the model are presented in figure 1. The wing had 76° sweepback of the leading-edge and circular-arc $2\frac{1}{2}$-percent-thick airfoil sections in the streamwise direction. Seven wing-body combinations were tested: a mid-wing model with 0° dihedral; high-wing models with 0°, 5°, and -5° dihedral; and low-wing models with 0°, 5°, and -5° dihedral. These models were made of brass and were of cast-unit-type construction.

Tunnel

Tests were conducted in both the low and high Mach number test sections of the Langley Unitary Plan wind tunnel, which is a variable-pressure continuous-flow tunnel. The test sections are approximately 4 feet square and 7 feet long. The nozzles leading to the test sections are of the asymmetric sliding-block type which permits a continuous variation in Mach number from about 1.5 to 2.9 in the low Mach number test section and from about 2.3 to 4.7 in the high Mach number test section.

Test Conditions

The test conditions for the investigation were as follows:

Mach number	Stagnation temperature, ^{o}F	Stagnation pressure, lb/sq in.		Reynolds number, per foot	
		Longitudinal data	Lateral data	Longitudinal data	Lateral data
1.60	150	11.88	7.92	3.0×10^6	2.0×10^6
1.90	150	13.21	8.81	3.0	2.0
2.30	150	15.92	10.61	3.0	2.0
2.96	150	22.79	15.17	3.0	2.0
3.96	175	45.80	45.80	3.4	3.4
4.63	175	70.18	70.18	3.8	3.8

The configurations were tested through an angle-of-attack range from about -4^{o} to 20^{o} and through an angle-of-sideslip range from about -4^{o} to 8^{o}. The stagnation dewpoint was maintained at -30^{o} F in order to avoid condensation effects.

Transition was produced by 1/16-inch-wide strips of carborundum grains affixed around the body 1/2 inch from the nose and on the wing 1/2 inch from the leading edge in a streamwise direction. No. 60 grit was used for the nose and No. 80 grit for the wings.

Measurements

Aerodynamic forces and moments were measured by means of a six-component electrical strain-gage balance housed within the model. The balance, in turn, was rigidly fastened to a sting support and thence to the tunnel-support system. The balance-chamber pressure was measured for each model and test condition.

Accuracy

The accuracy of the individual measured quantities, based on calibrations and repeatability of data, is estimated to be within the following limits:

C_D	±0.0003
C_L	±0.003
C_l	±0.0001
C_m	±0.0004
C_n	±0.0002
C_Y	±0.0015
α, deg	±0.10
β, deg	±0.10
Mach numbers 1.60 to 2.96	±0.015
Mach numbers 3.96 and 4.63	±0.050

Corrections

Angles of attack were corrected for tunnel flow angularity, and angles of attack and sideslip were corrected for deflection of the balance and sting support due to aerodynamic loads. The results were adjusted to correspond to free-stream static conditions at the base of the model.

PRESENTATION OF RESULTS

The results of the investigation are presented in the following figures:

	Figure
Effect of Reynolds number on aerodynamic characteristics for mid-wing configuration, M = 2.96	2
Typical aerodynamic characteristics in sideslip	3
Effect of wing height on sideslip parameters	4
Effect of geometric dihedral on sideslip parameters for high-wing configuration	5
Effect of geometric dihedral on sideslip parameters for low-wing configuration	6
Effect of wing height on aerodynamic characteristics in pitch	7
Effect of geometric dihedral on aerodynamic characteristics in pitch for high-wing configuration	8
Effect of geometric dihedral on aerodynamic characteristics in pitch for low-wing configuration	9

DISCUSSION

The pitch characteristics discussed in this paper were obtained at a wind-tunnel Reynolds number per foot of 3×10^6. Because of strain-gage-balance limitations, however, the sideslip data were obtained at a Reynolds number per foot of 2×10^6. A comparison of the results obtained on the mid-wing configuration at a Mach number of 2.96 and at Reynolds numbers of both 2 and 3×10^6 (fig. 2) indicates that other than the expected differences in drag coefficient and L/D there is no effect of this change in Reynolds number on the longitudinal characteristics or the sideslip parameters of the configuration.

Sideslip Characteristics

Basic aerodynamic characteristics in sideslip for the high-wing configuration with 5° and -5° dihedral are presented in figure 3 for angles of attack to about 17°. This figure is presented primarily to indicate the linearity of the data since the sideslip parameters presented in this paper were obtained from incremental results of tests made through the angle-of-attack range at sideslip angles of about 0° and 4°.

The effect of wing height on the sideslip parameters is shown in figure 4. These data indicate that, with respect to the mid-wing position, changing to a high wing provides an increase in effective dihedral, whereas changing to a low wing provides an essentially equal decrease in effective dihedral at all Mach numbers and angles of attack of the investigation. There is, however, generally a slight decrease in the effect of wing height on C_{l_β} at the higher angles of attack of the investigation. There is no significant effect of Mach number on the increment of C_{l_β} provided by wing height, although the variation of C_{l_β} with α decreases with increasing Mach number, as would be expected. The empirical relation $\Delta C_{l_\beta} = \dfrac{1.2\sqrt{A}\left(\frac{3}{b}\right)\left(\frac{h+w}{b}\right)}{57.3}$ which was used for estimating wing height effects on effective dihedral at low speeds (ref. 3) and which provided reasonably good agreement with results presented in reference 4 at $M = 2.01$, also indicates good agreement with the results presented herein at Mach numbers to 4.63.

At angles of attack near 0°, changing to either the high- or the low-wing configuration resulted in an increase in directional instability at all Mach numbers (fig. 4). With increasing angle of attack, the high-wing configuration becomes increasingly unstable, while the loss in stability for the low-wing configuration becomes less than that for the mid-wing configuration. These results are opposite to the results reported in references 4 and 5, wherein it was shown that, with respect to a mid-wing configuration, a high-wing configuration became less unstable directionally with increasing angle of attack and a low-wing configuration became increasingly unstable directionally. This opposite trend for the present configuration results from the fact that the moment

center is considerably further rearward, so that most of the pressure field transmitted from the wing to the body is forward of the moment center and thus provides a destabilizing moment in sideslip.

The effect of geometric dihedral on the high- and low-wing configurations is presented in figures 5 and 6, respectively. The results indicate that positive and negative geometric dihedral provide positive and negative increments of effective dihedral, respectively, throughout the angle-of-attack and Mach number ranges of the investigation, although the increments do decrease slightly with increasing Mach number. The results in figures 5 and 6 indicate that 5° geometric dihedral is approximately equivalent to the effective dihedral provided by wing height for this configuration. In other words, the positive dihedral effect provided by the high wing and the negative dihedral effect provided by the low wing are essentially offset by the use of -5° geometric dihedral with the high wing and 5° geometric dihedral with the low wing. At angles of attack near 0°, geometric dihedral has little or no effect on the directional stability of either the low- or high-wing configurations. At higher angles of attack, however, negative geometric dihedral noticeably reduces the directional stability, whereas positive geometric dihedral leads to slightly higher levels of directional stability.

Longitudinal Characteristics

There are only small effects of wing height (fig. 7) or geometric dihedral (figs. 8 and 9) on the lift-curve slope or the longitudinal stability in the low-lift range. However, the results indicate a nonlinear variation of C_m with C_L at higher lifts such that, with respect to the mid-wing configuration, the low wing provides lower stability and the high wing provides higher stability. The use of either positive or negative geometric dihedral is generally slightly destabilizing at high lift.

Both the high- and the low-wing positions result in an increase in minimum drag over that for the mid-wing position but the variations in drag due to lift are such that no consistent effects of wing height on maximum L/D were obtained over the Mach number range of the investigation. The use of geometric dihedral with the high-wing configuration (fig. 8) indicates that the maximum values of L/D tend to increase with positive dihedral and decrease with negative dihedral. The results for the low-wing configuration (fig. 9) indicate an increase in the maximum value of L/D with either positive or negative dihedral. Although these variations in maximum L/D with dihedral are relatively small with respect to the accuracy attainable, the results are constant with changing Mach number.

CONCLUSIONS

Results of tests to determine the effect of wing height and geometric dihedral on the aerodynamic characteristics of a highly swept arrow wing-body configuration at Mach numbers from 1.60 to 4.63 indicate the following conclusions:

1. The high wing provided a positive increment of effective dihedral and the low wing provided a negative increment of effective dihedral, each of which was essentially constant with changing Mach number.

2. Plus and minus 5° geometric dihedral, respectively, provided positive and negative increments of effective dihedral that were approximately equivalent to the values of effective dihedral provided by the wing height change for these configurations.

3. The geometry of the wing pressure field was such that with increasing angle of attack the high-wing configuration became increasingly unstable, whereas the loss in stability for the low-wing configuration became less than that for the mid-wing configuration.

4. There were only small effects of either wing height or geometric dihedral on the longitudinal stability characteristics of the configurations.

Langley Research Center,
National Aeronautics and Space Administration,
Langley Station, Hampton, Va., July 23, 1964.

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2. Spearman, M. Leroy; and Henderson, Arthur, Jr.: Some Effects of Aircraft Configuration on Static Longitudinal and Directional Stability Characteristics at Supersonic Mach Numbers Below 3. NACA RM L55L15a, 1956.

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4. Spearman, M. Leroy: Investigation of the Aerodynamic Characteristics in Pitch and Sideslip of a 45° Sweptback-Wing Airplane Model With Various Vertical Locations of the Wing and Horizontal Tail - Effect of Wing Location and Geometric Dihedral for the Wing-Body Combination, M = 2.01. NACA RM L55B18, 1955.

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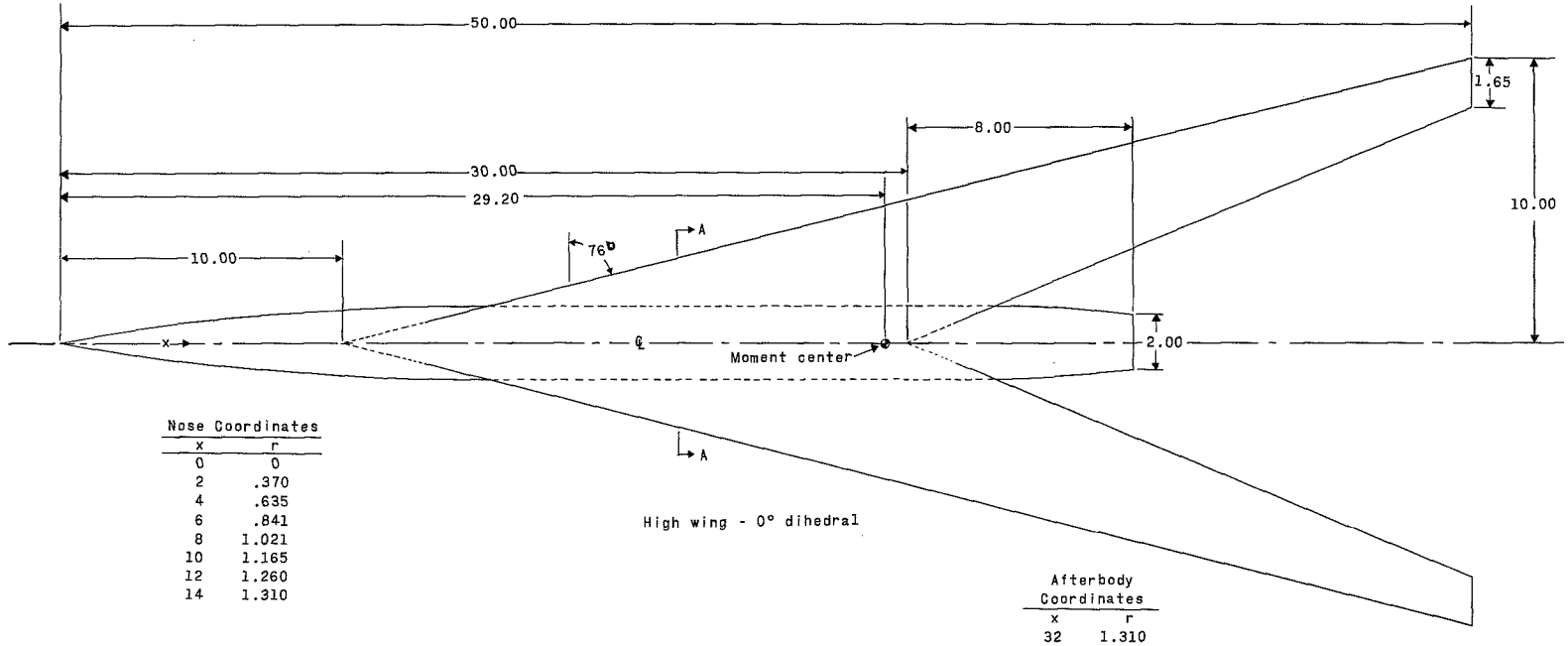
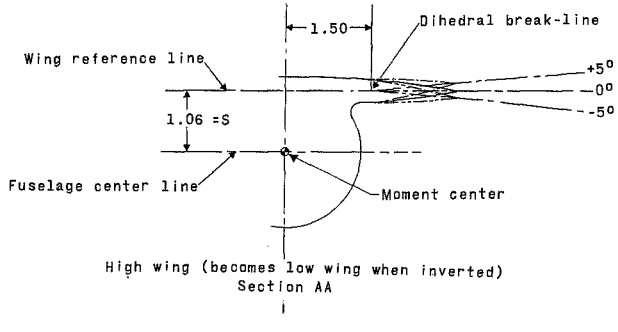
7. Boatright, William B.: Experimental Investigation of Effects of Wing Plan Form and Dihedral Angle on Sideslip Derivatives of Sweptback-Wing—Body Combinations at Supersonic Speeds. NACA RM L58E08, 1958.



Nose Coordinates	
x	r
0	0
2	.370
4	.635
6	.841
8	1.021
10	1.165
12	1.260
14	1.310

Afterbody Coordinates	
x	r
32	1.310
34	1.277
36	1.185
38	1.000



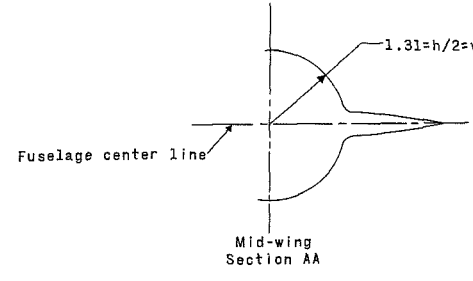
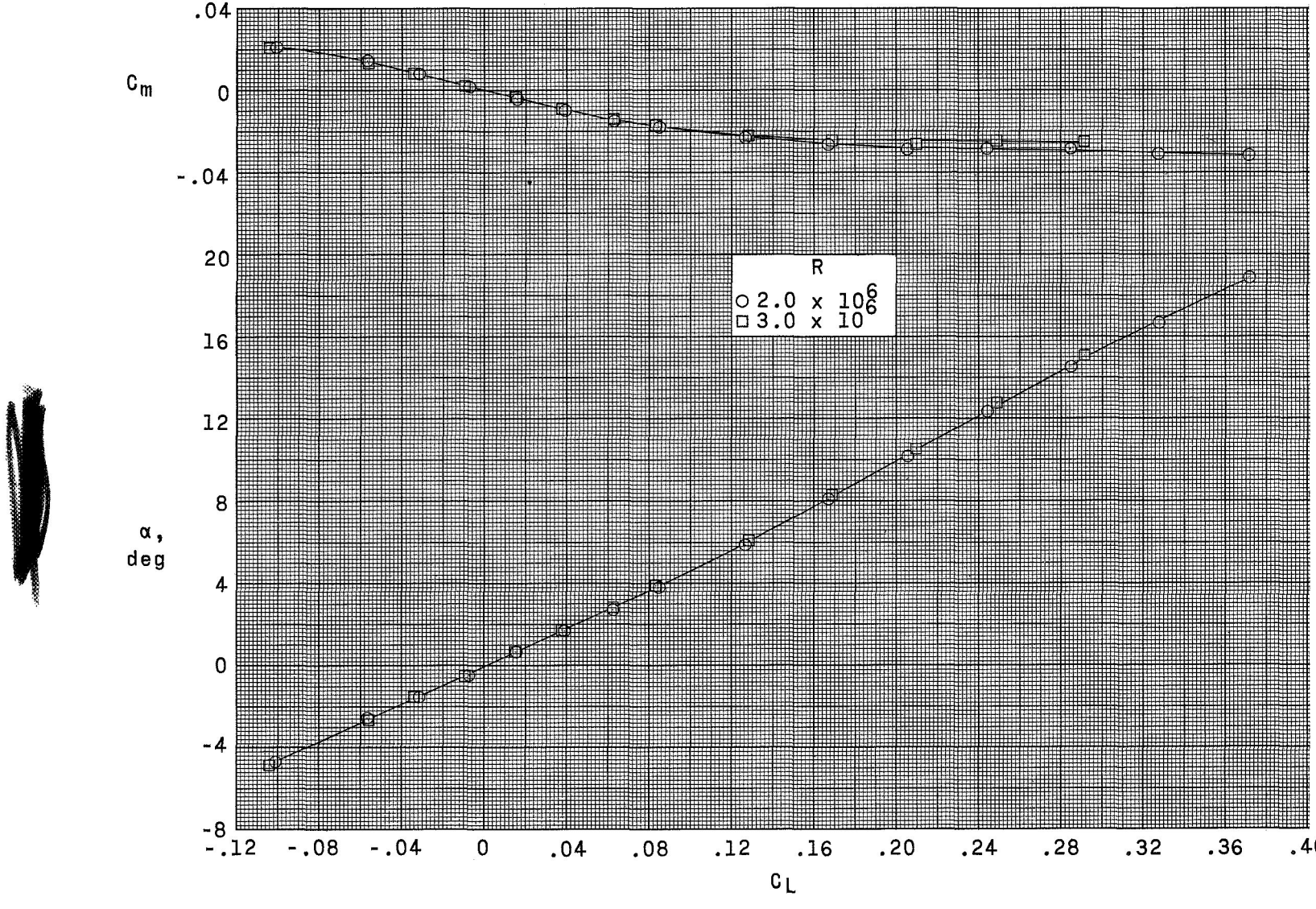
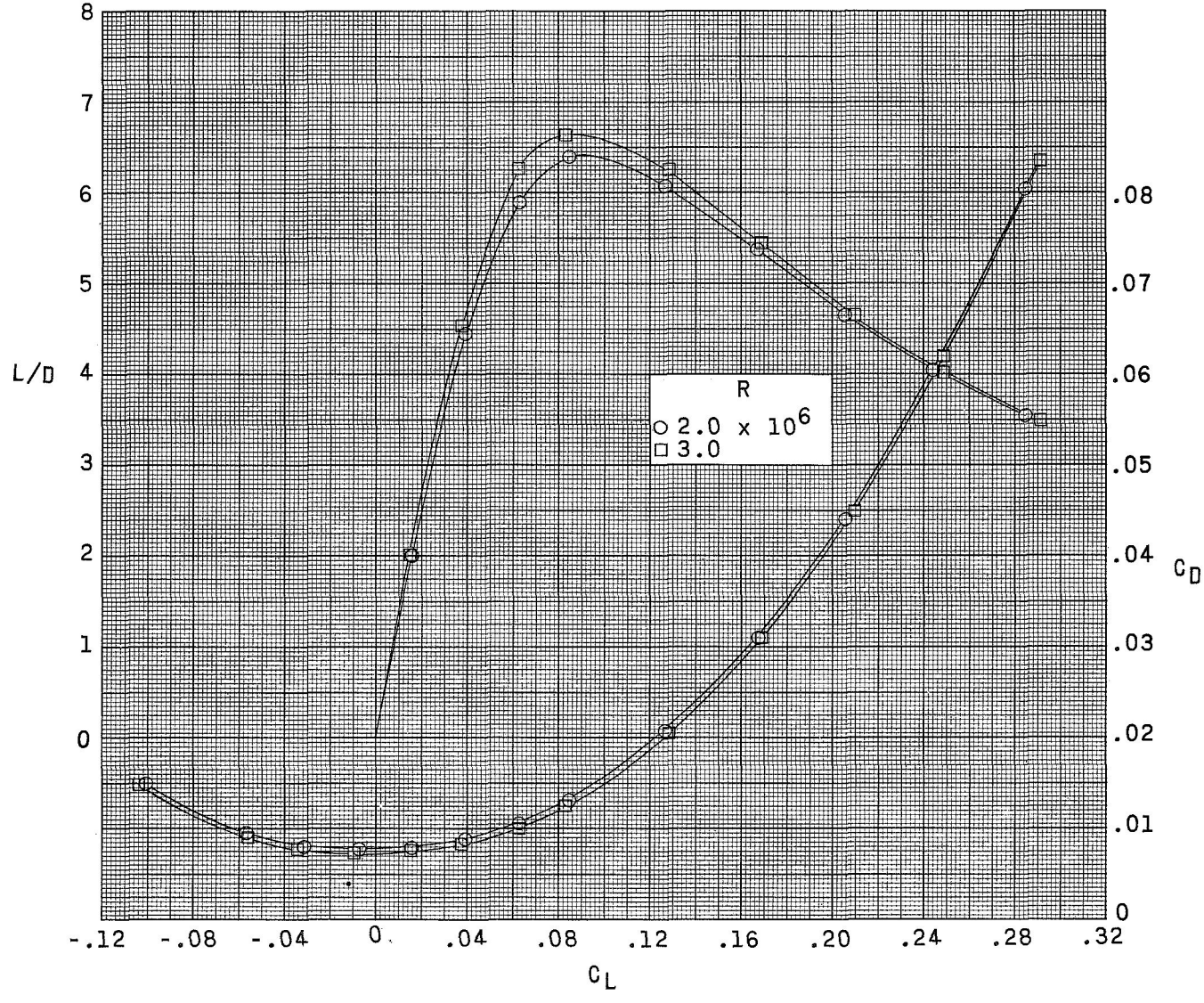


Figure 1.- Model details. (All dimensions are in inches unless otherwise noted.)



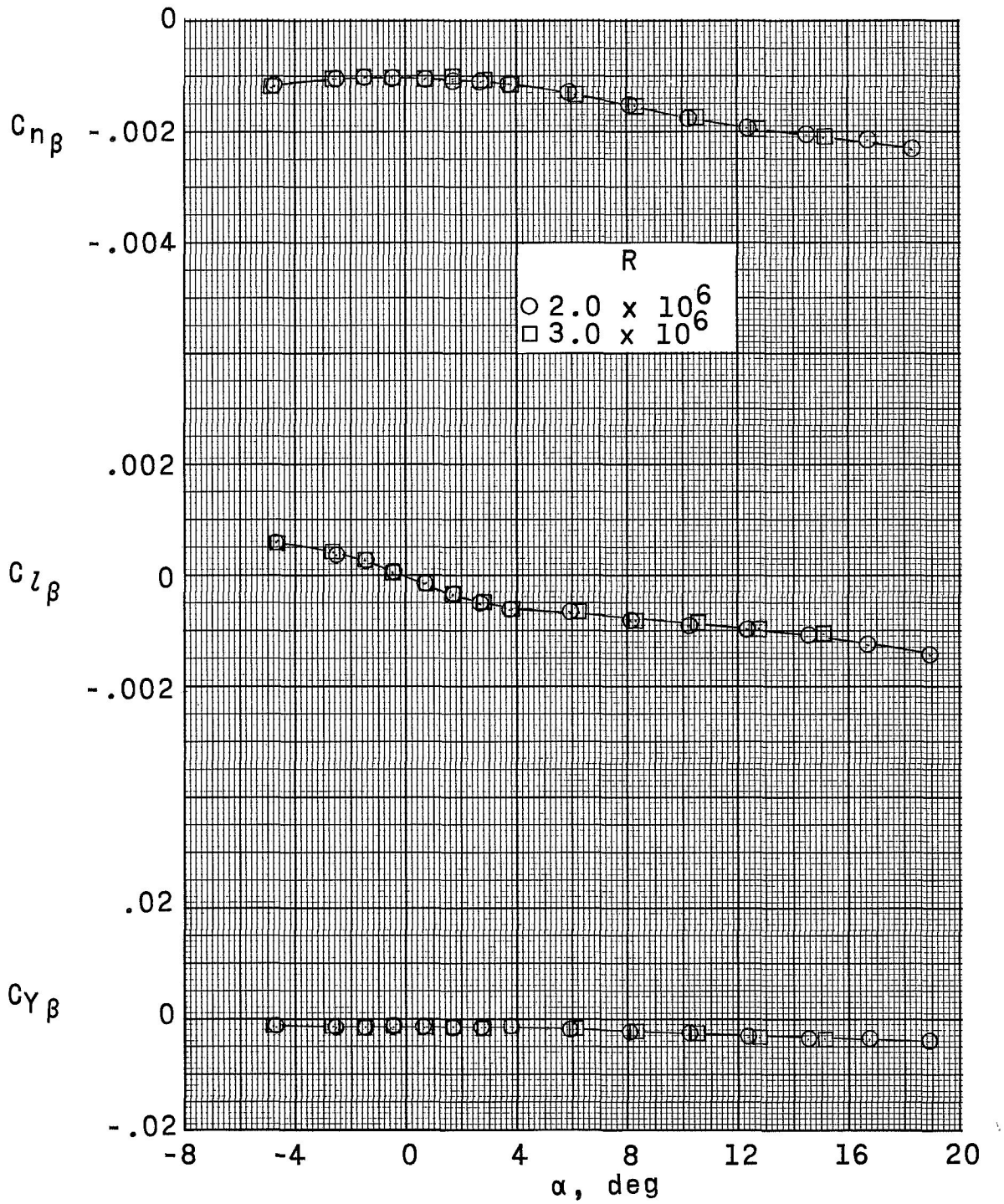
(a) Aerodynamic characteristics in pitch.

Figure 2.- Effect of Reynolds number on aerodynamic characteristics for mid-wing configuration. M = 2.96.



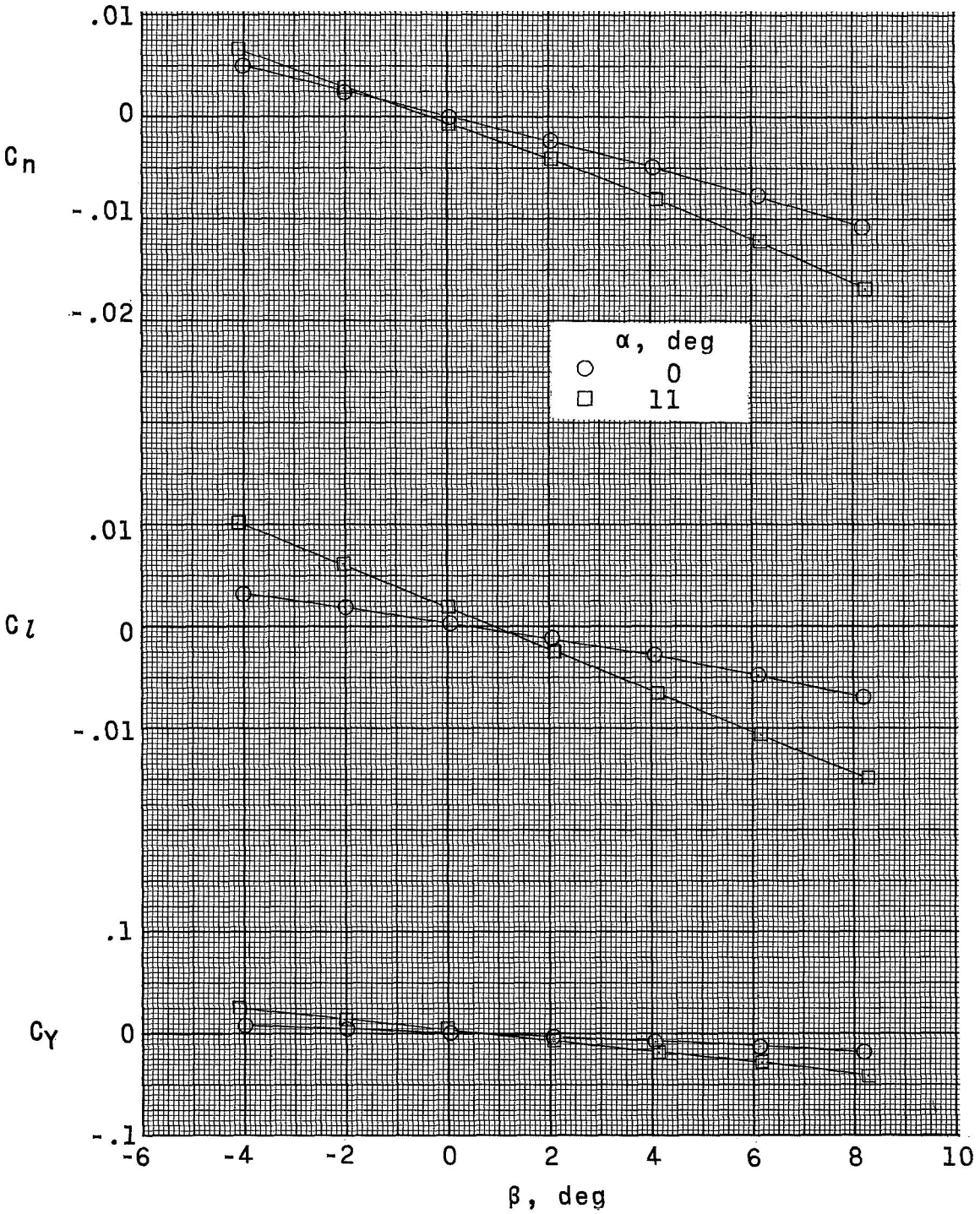
(a) Concluded.

Figure 2.- Continued.



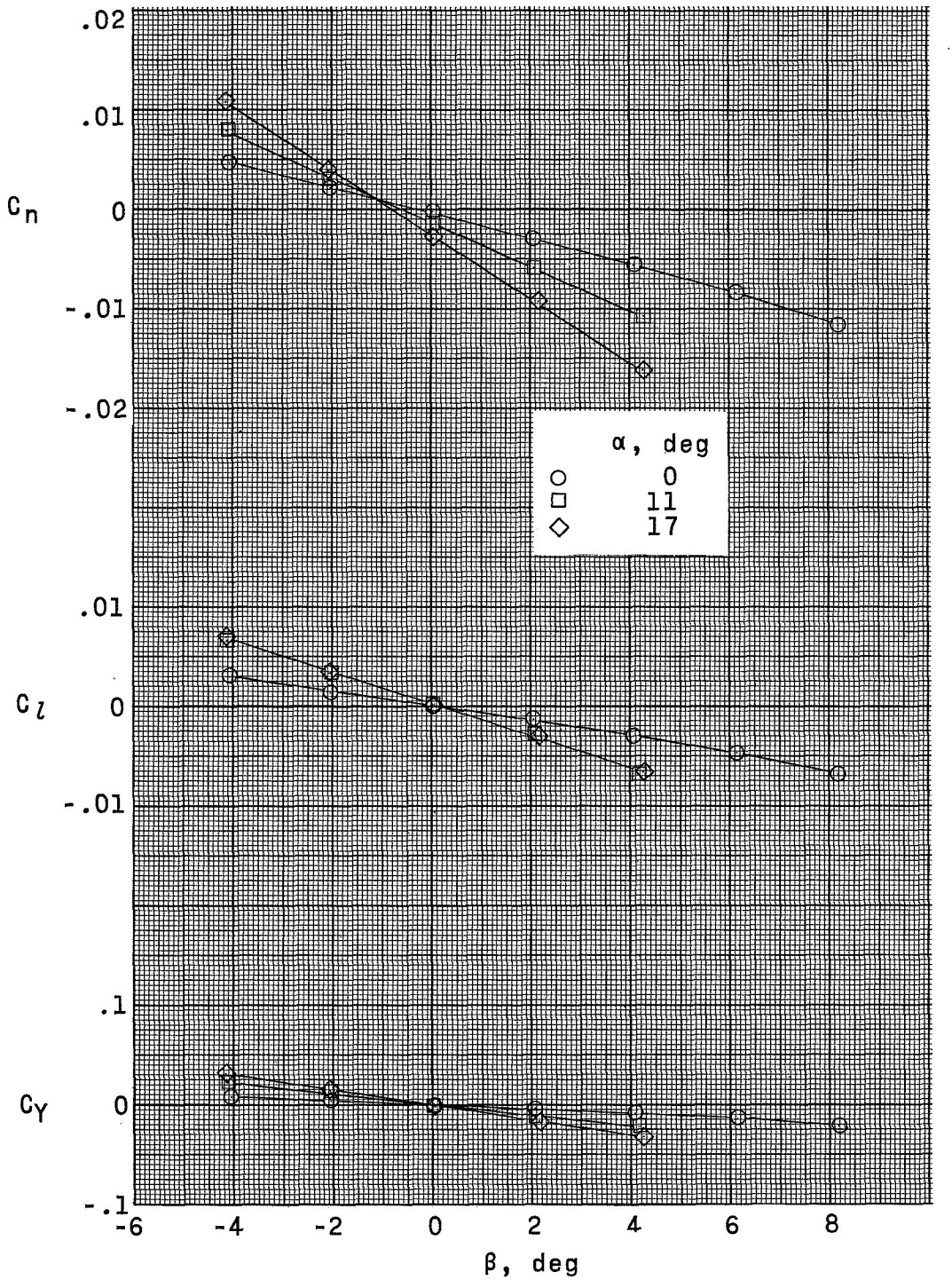
(b) Sideslip parameters.

Figure 2.- Concluded.



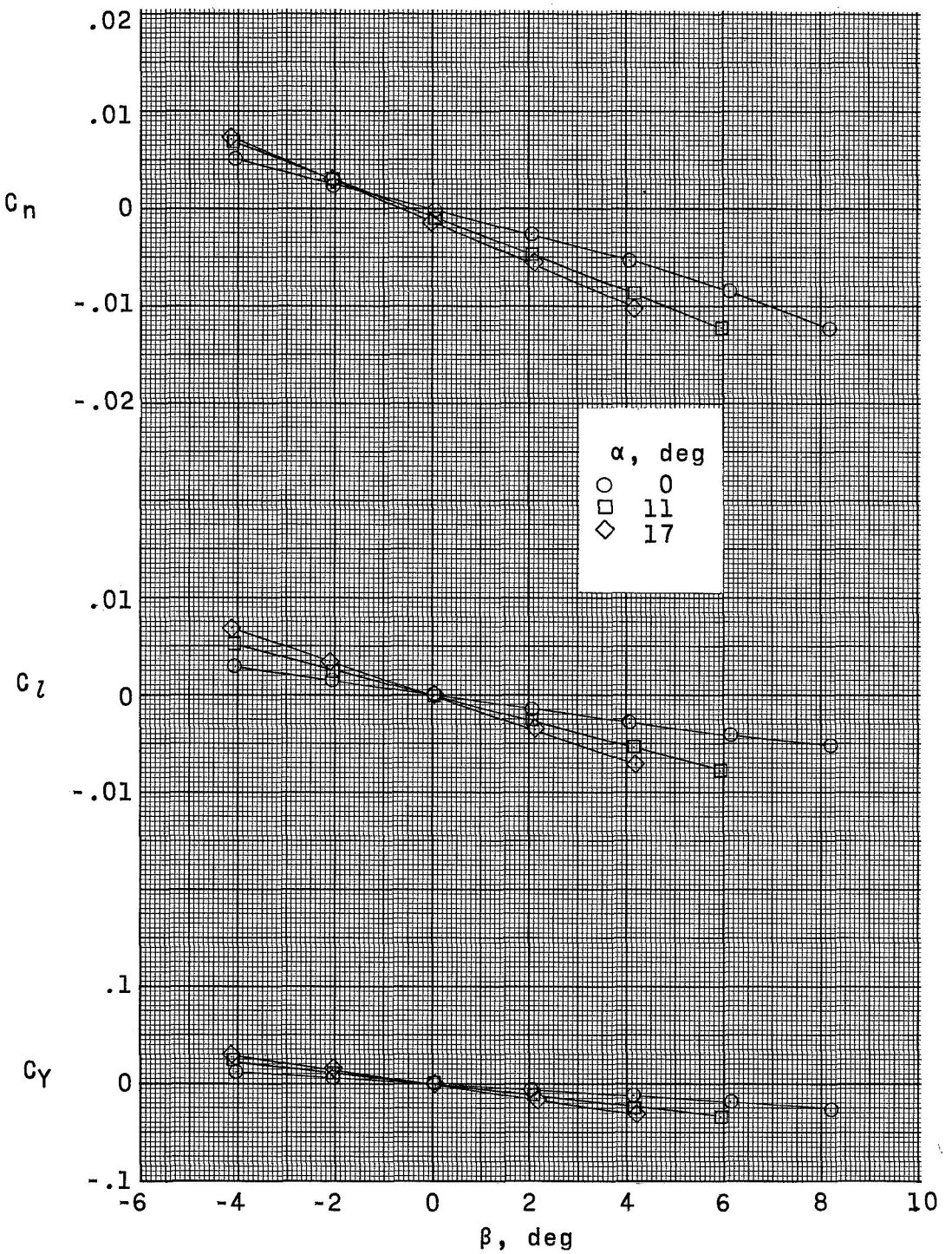
(a) High wing with 5° dihedral; M = 1.60.

Figure 3.- Typical aerodynamic characteristics in sideslip.



(a) Continued; M = 2.30.

Figure 3.- Continued.



(a) Concluded; M = 4.63.

Figure 3.- Continued.

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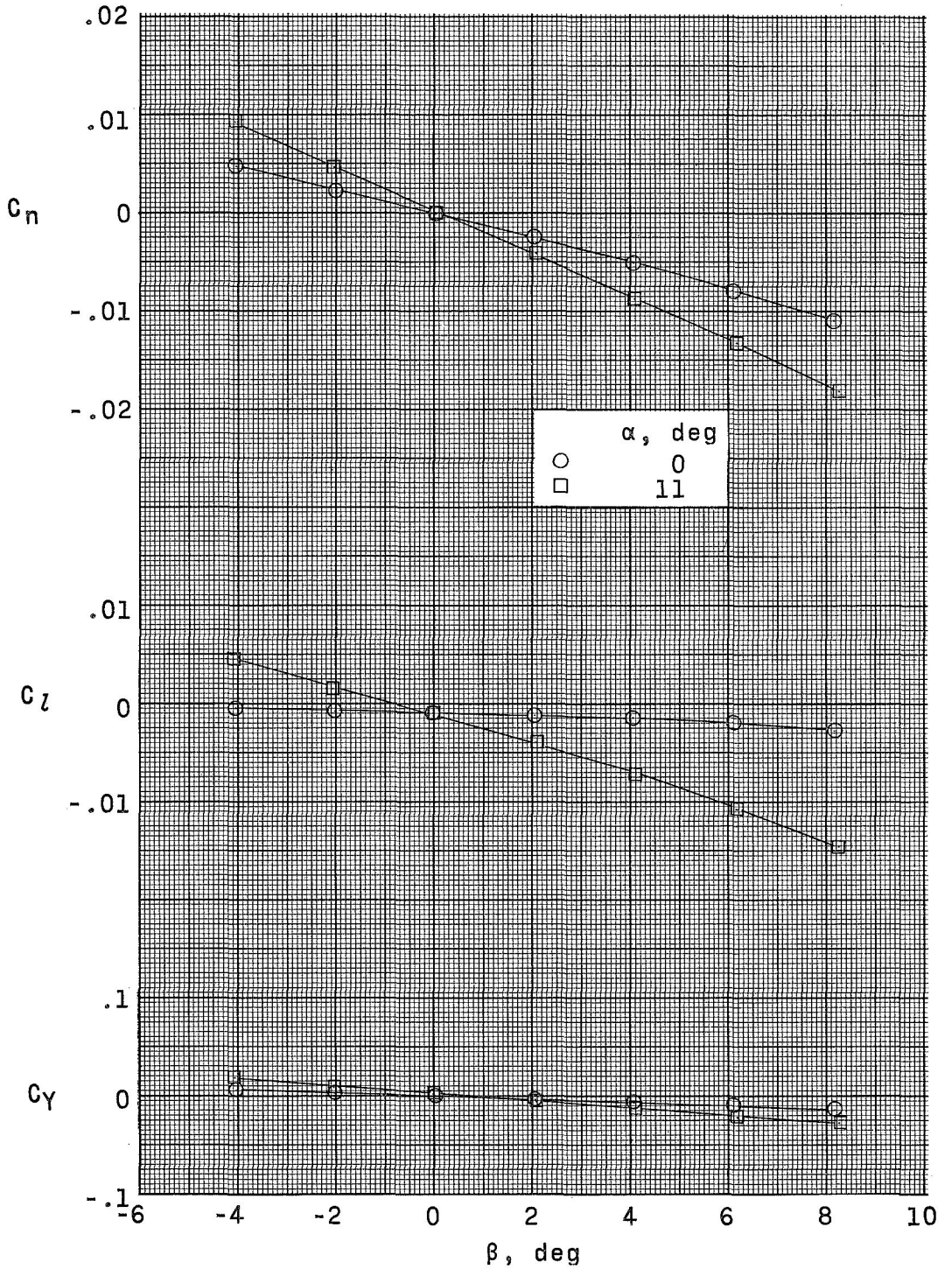
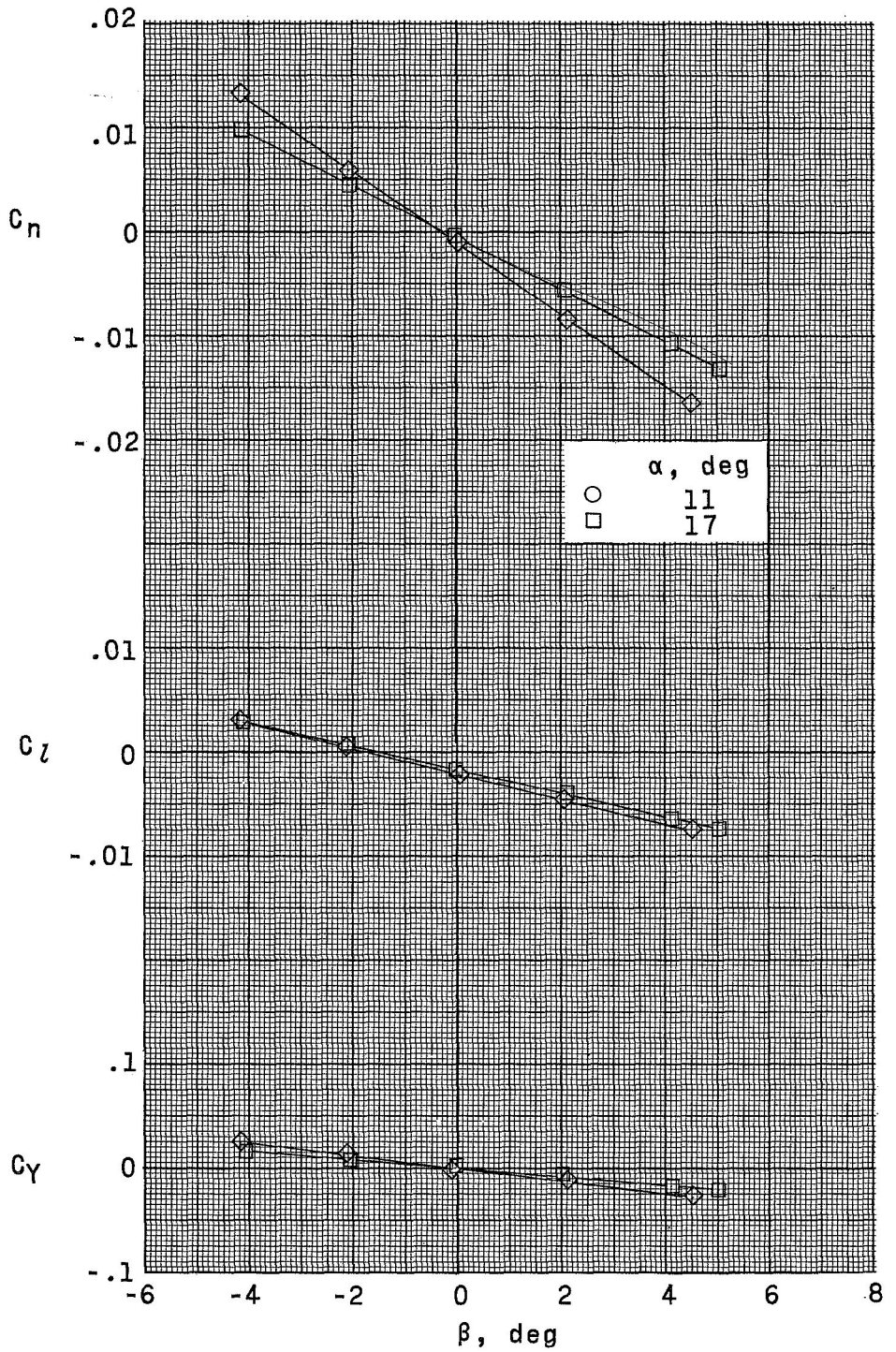


(b) High wing with -5° dihedral; M = 1.60.

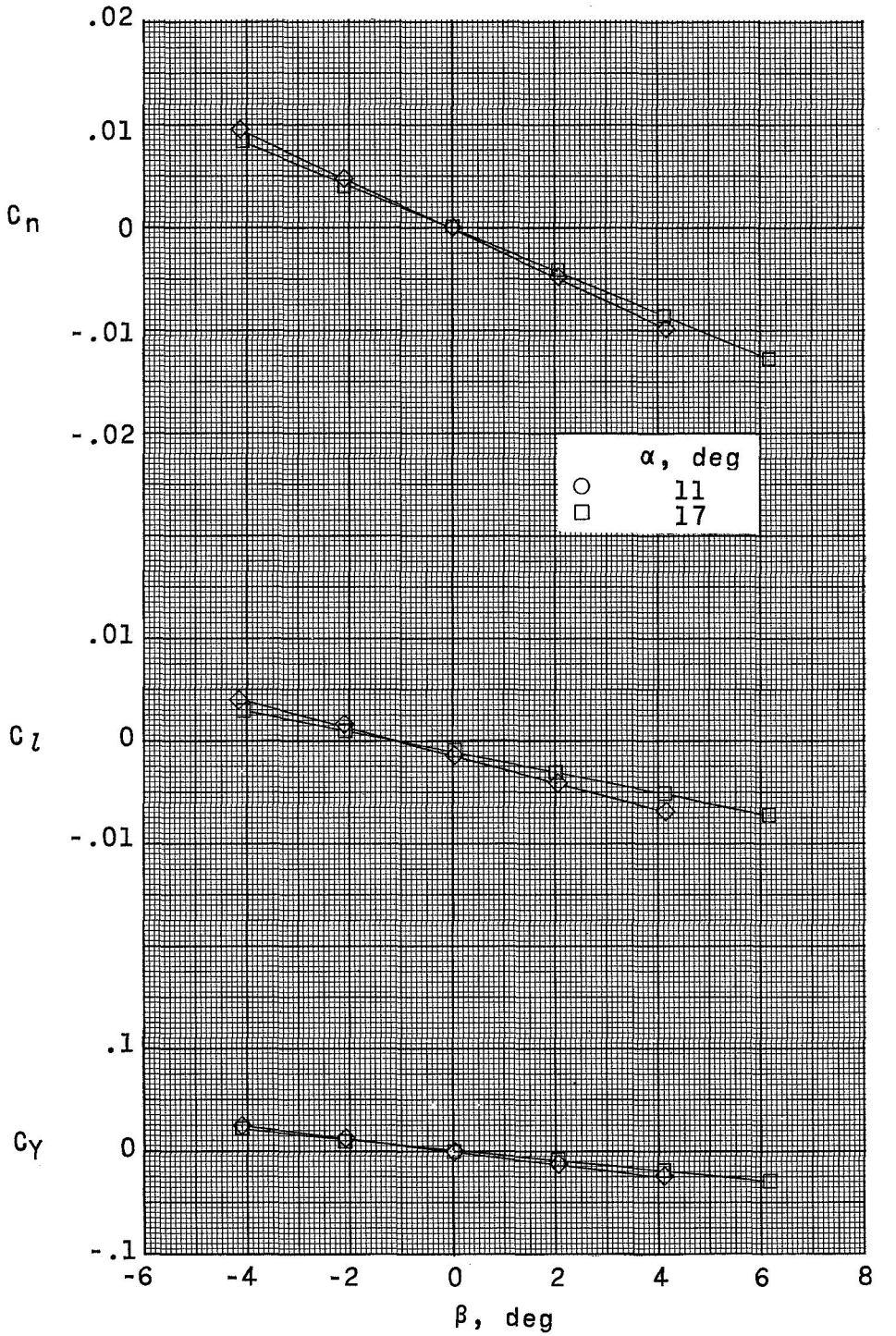
Figure 3.- Continued.

[redacted]



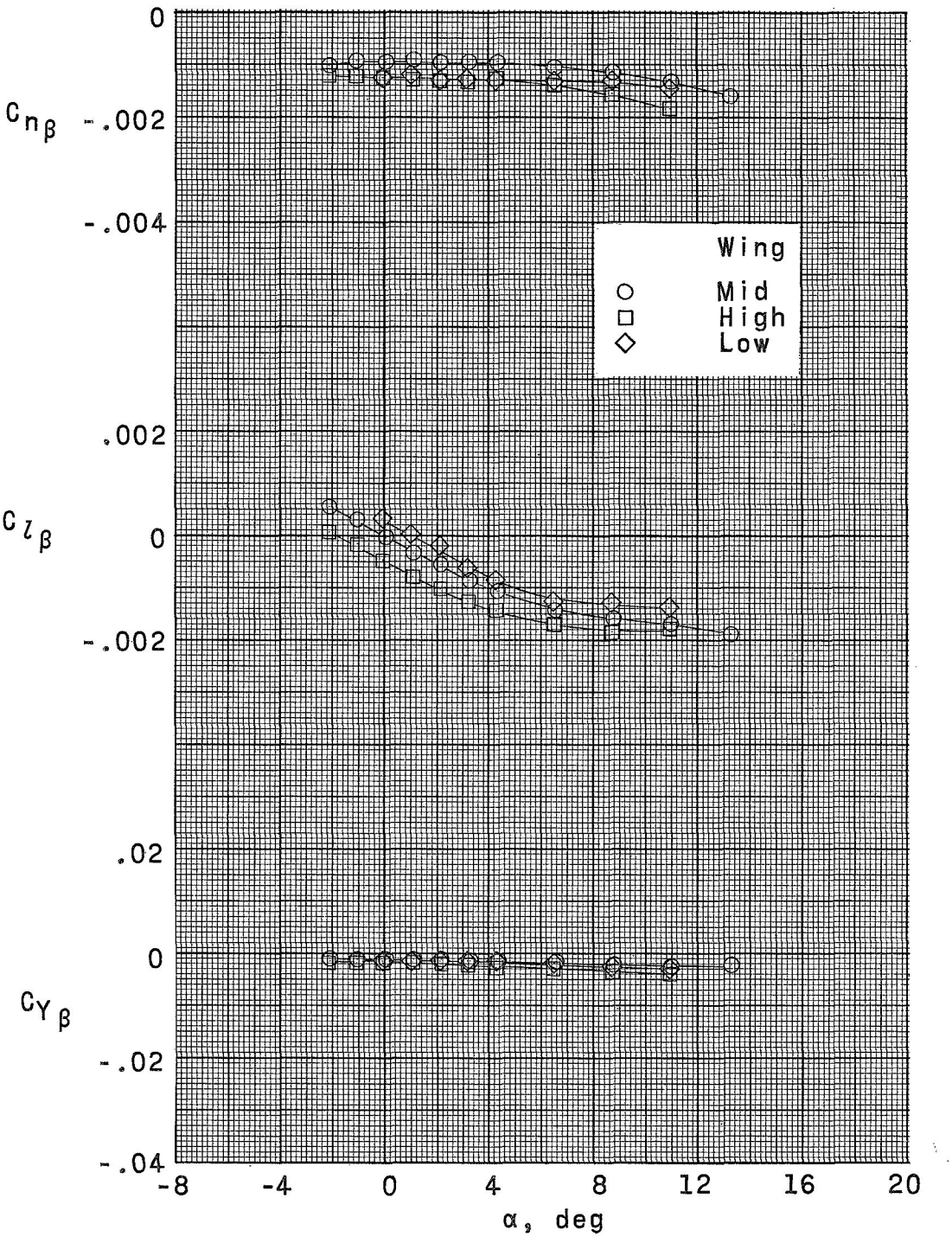
(b) Continued; M = 2.30.

Figure 3.- Continued.



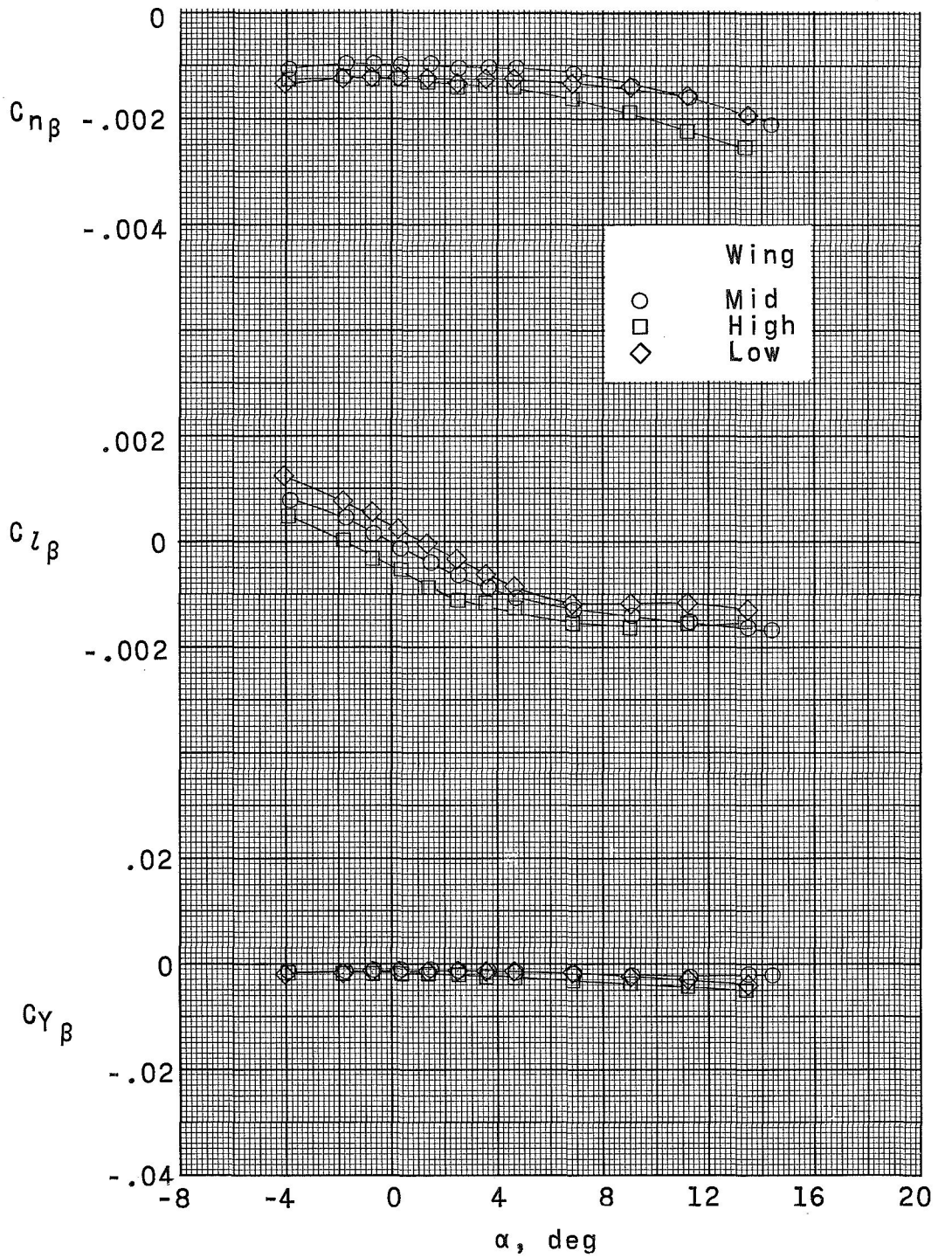
(b) Concluded; M = 4.63.

Figure 3.- Concluded.



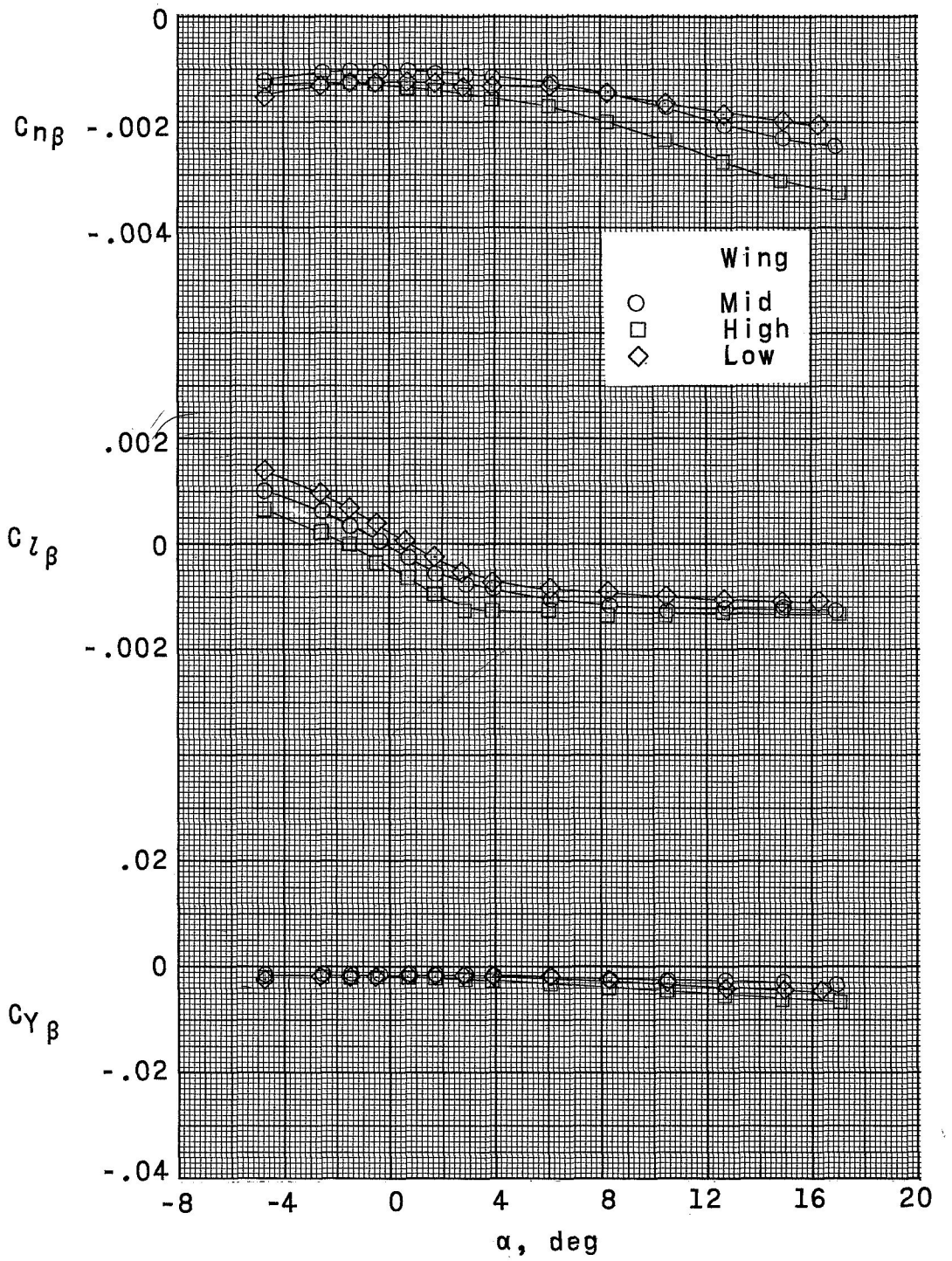
(a) M = 1.60.

Figure 4.- Effect of wing height on sideslip parameters.



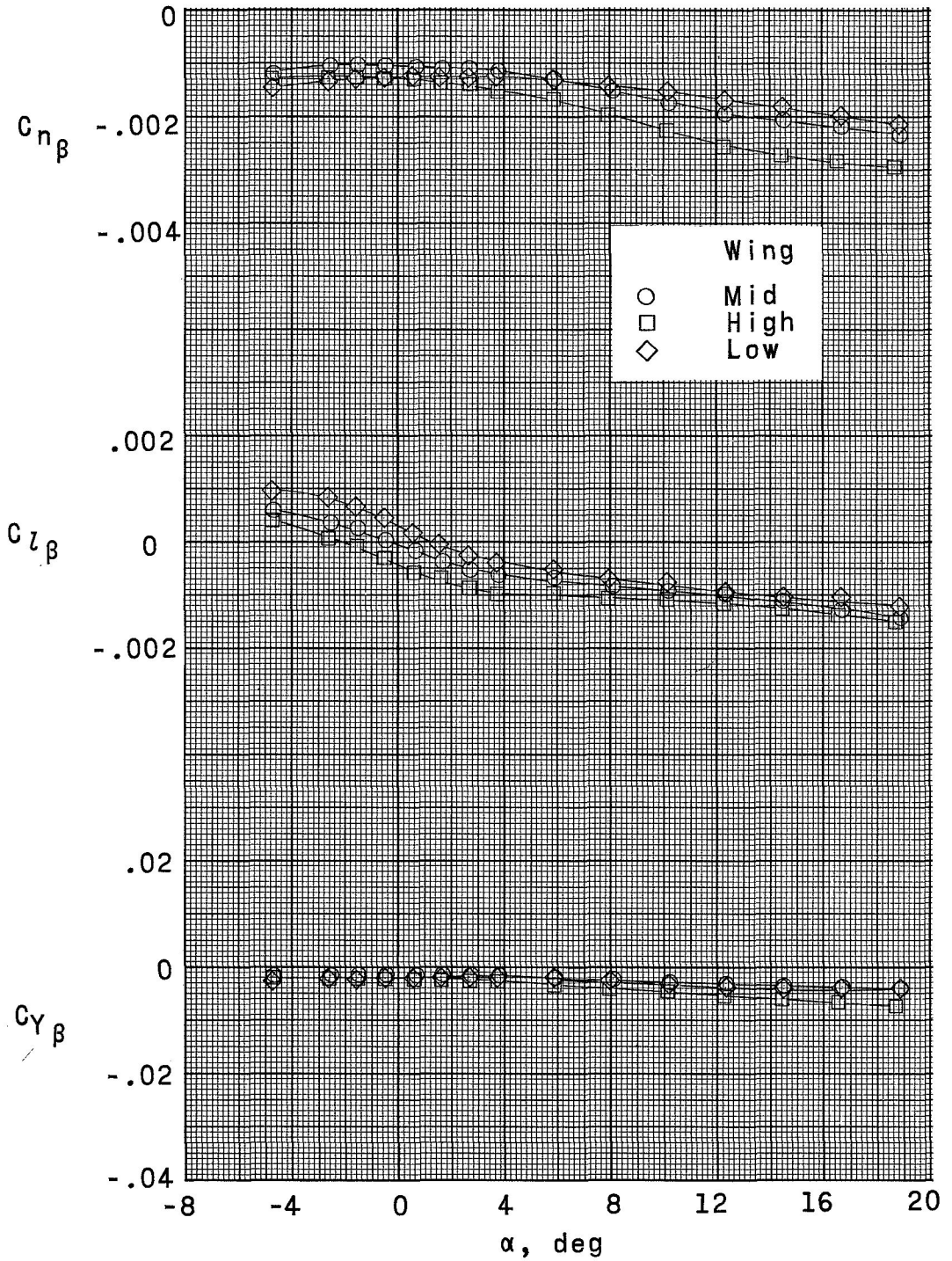
(b) M = 1.90.

Figure 4.- Continued.



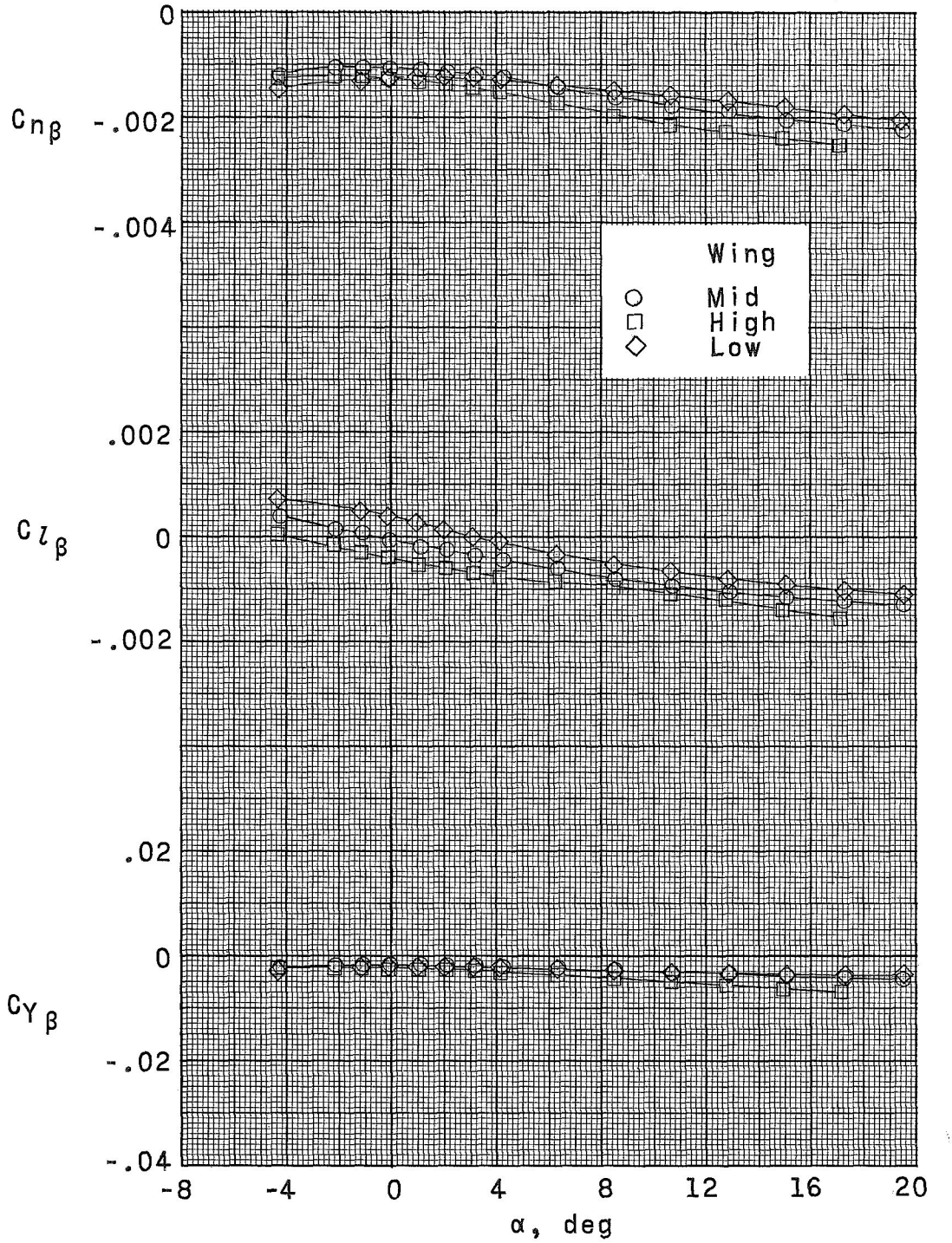
(c) M = 2.30.

Figure 4.- Continued.



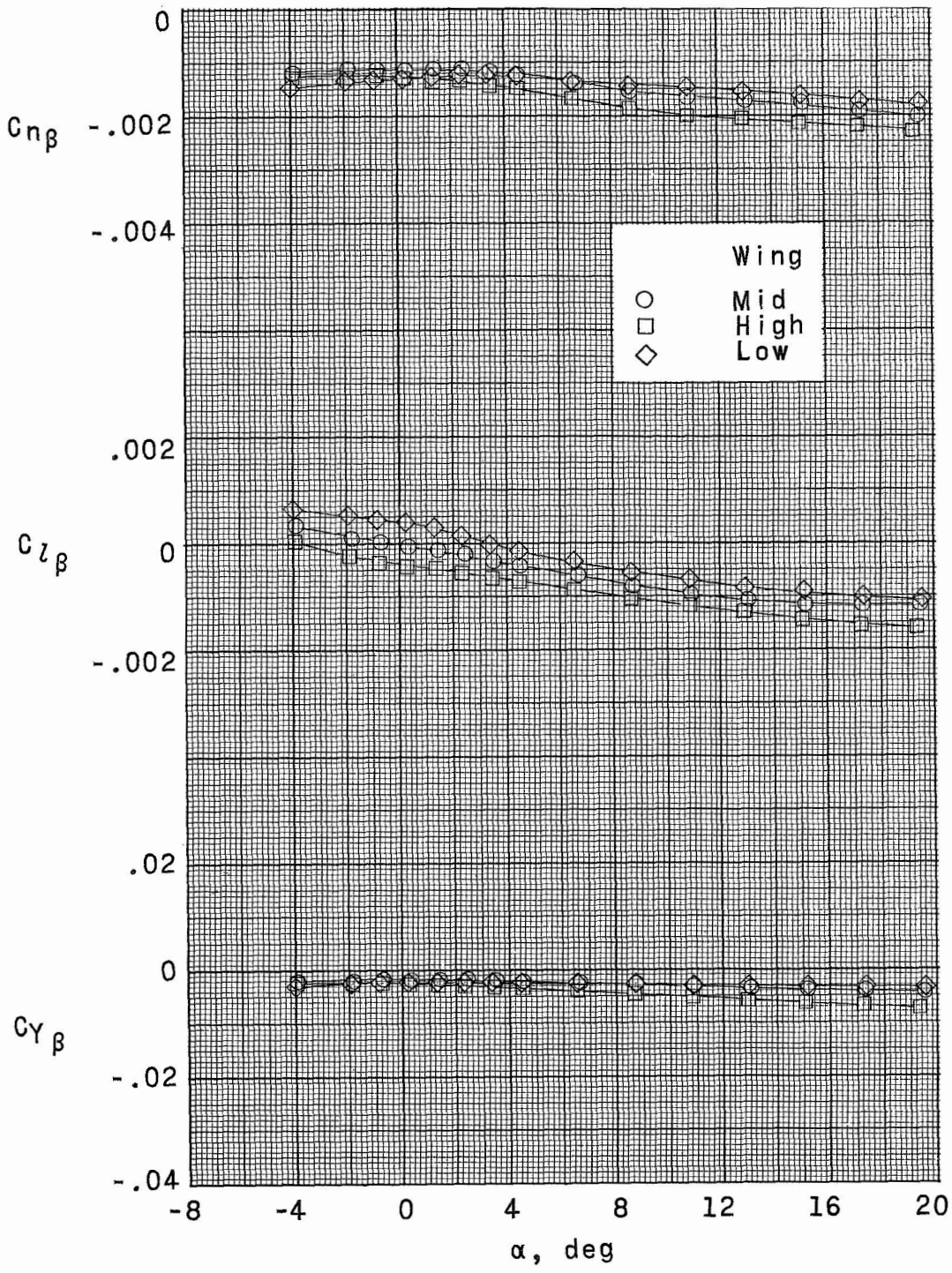
(d) M = 2.96.

Figure 4.- Continued.



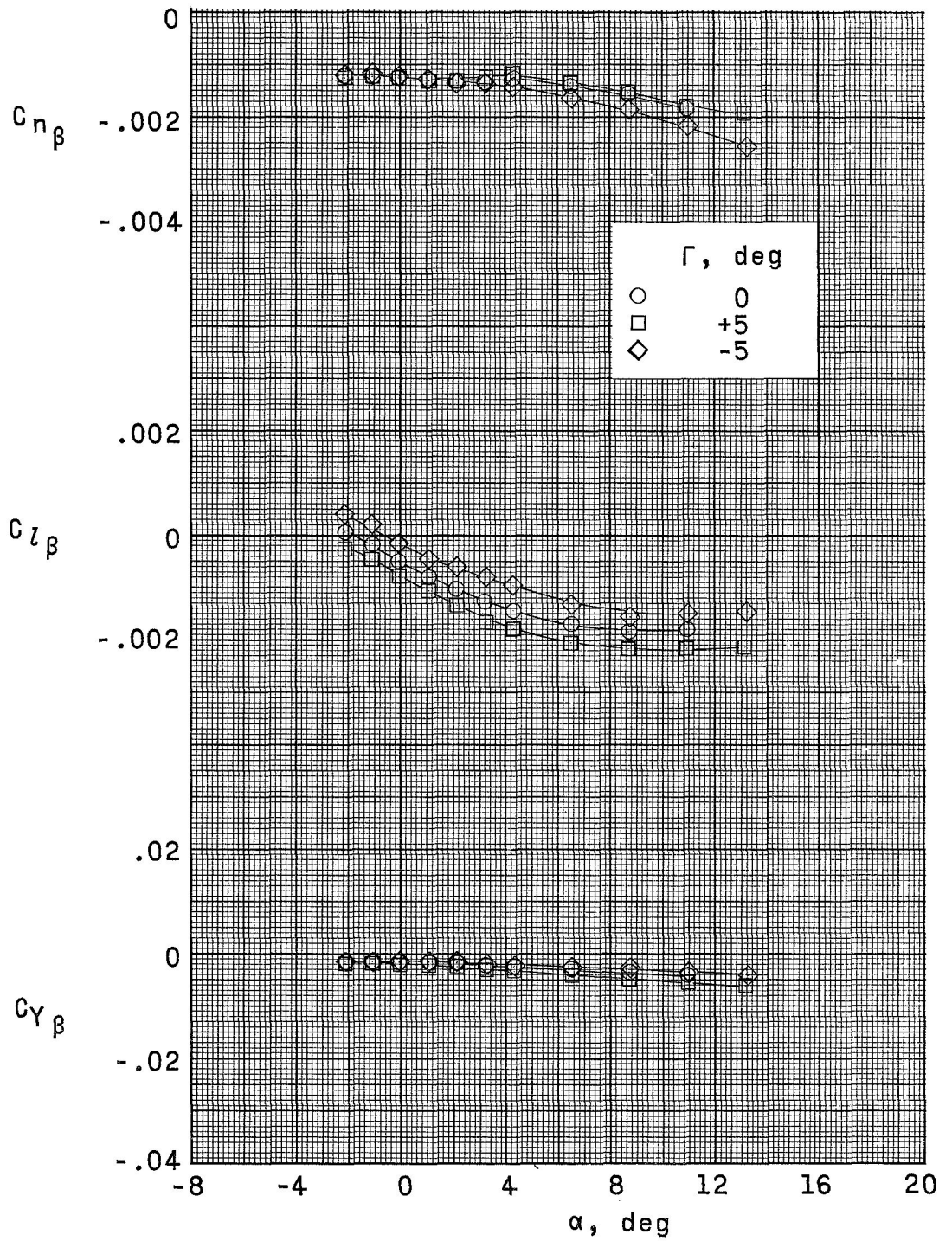
(e) M = 3.96.

Figure 4.- Continued.



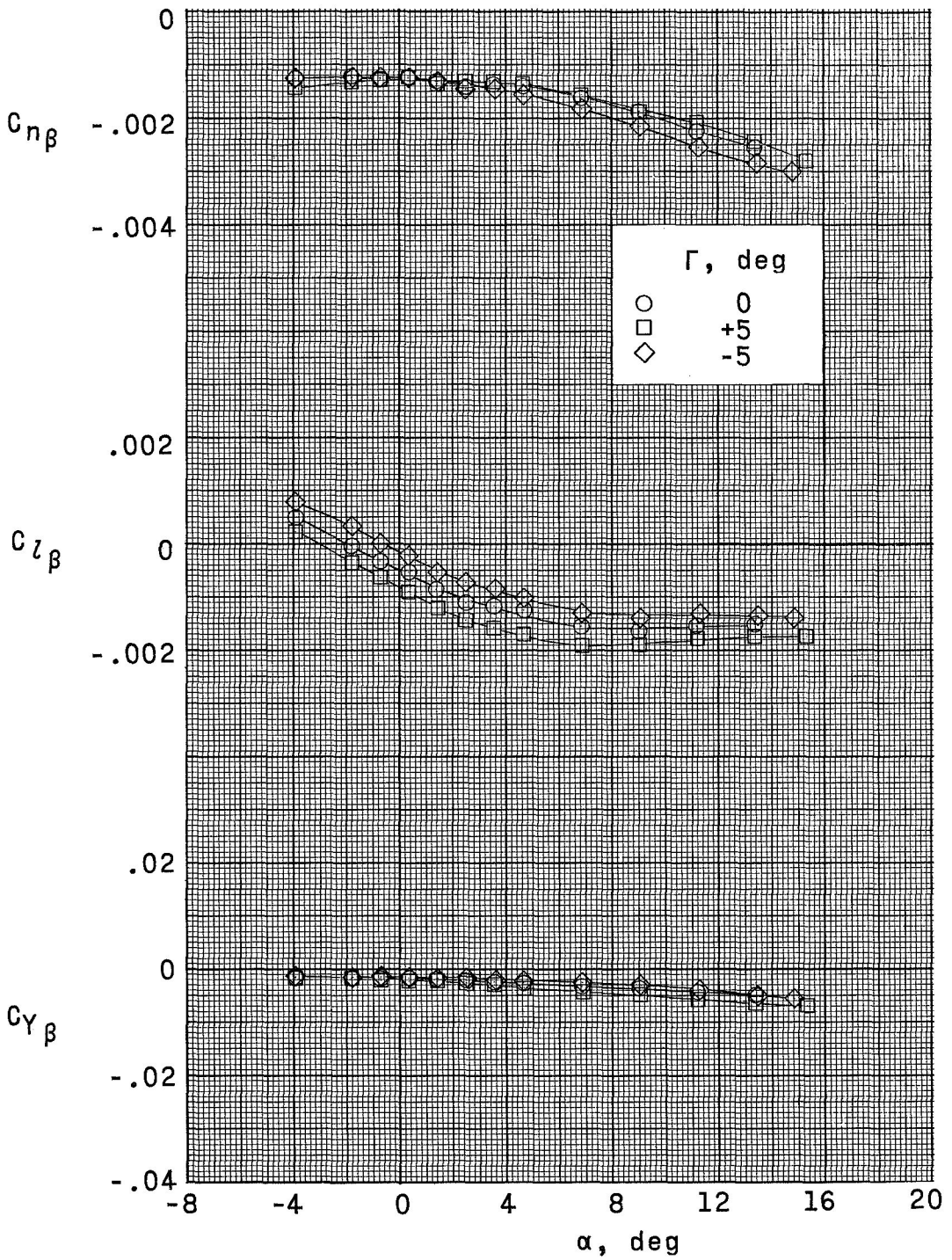
(f) M = 4.63.

Figure 4.- Concluded.



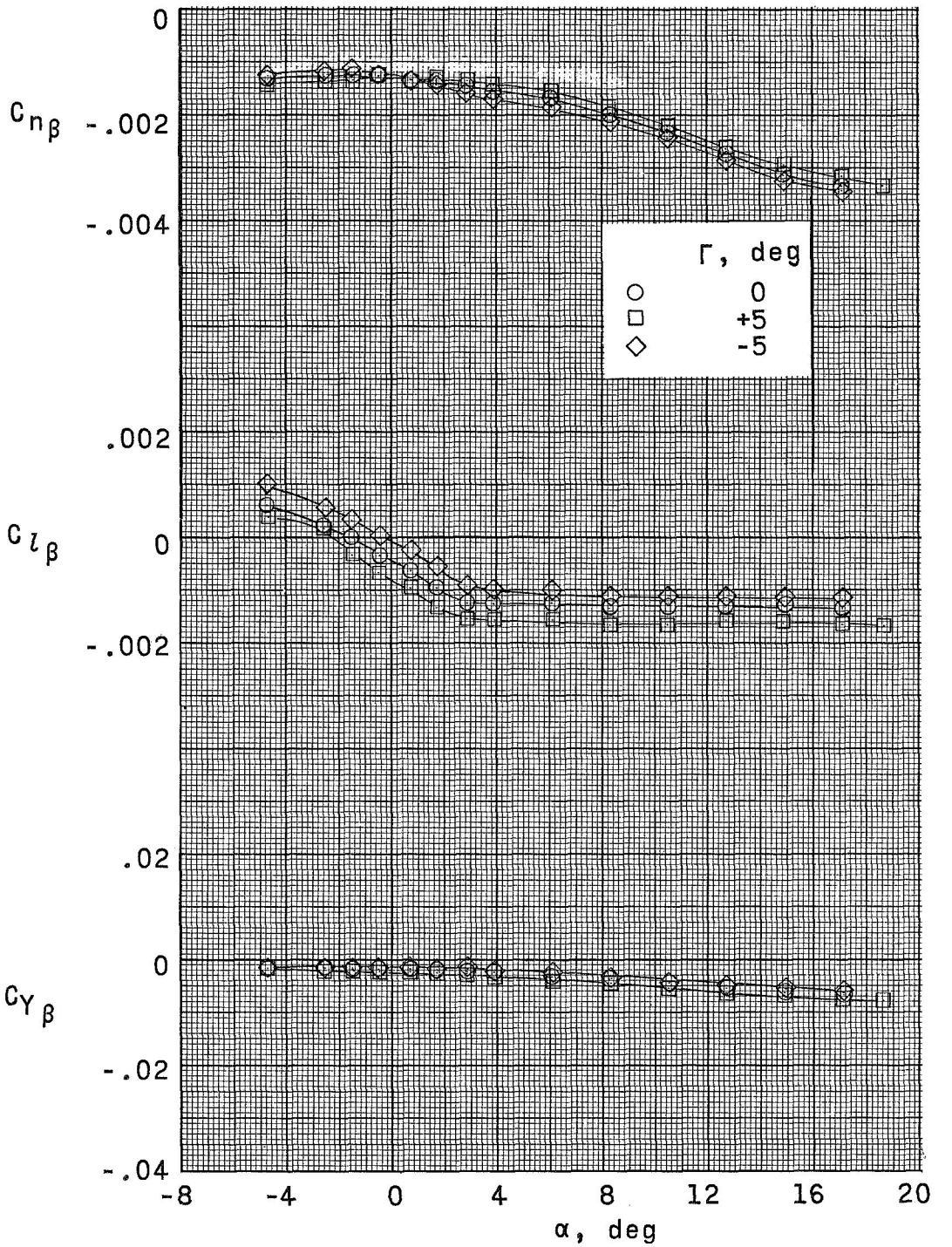
(a) M = 1.60.

Figure 5.- Effect of geometric dihedral on sideslip parameters for high-wing configuration.



(b) M = 1.90.

Figure 5.- Continued.



(c) M = 2.30.

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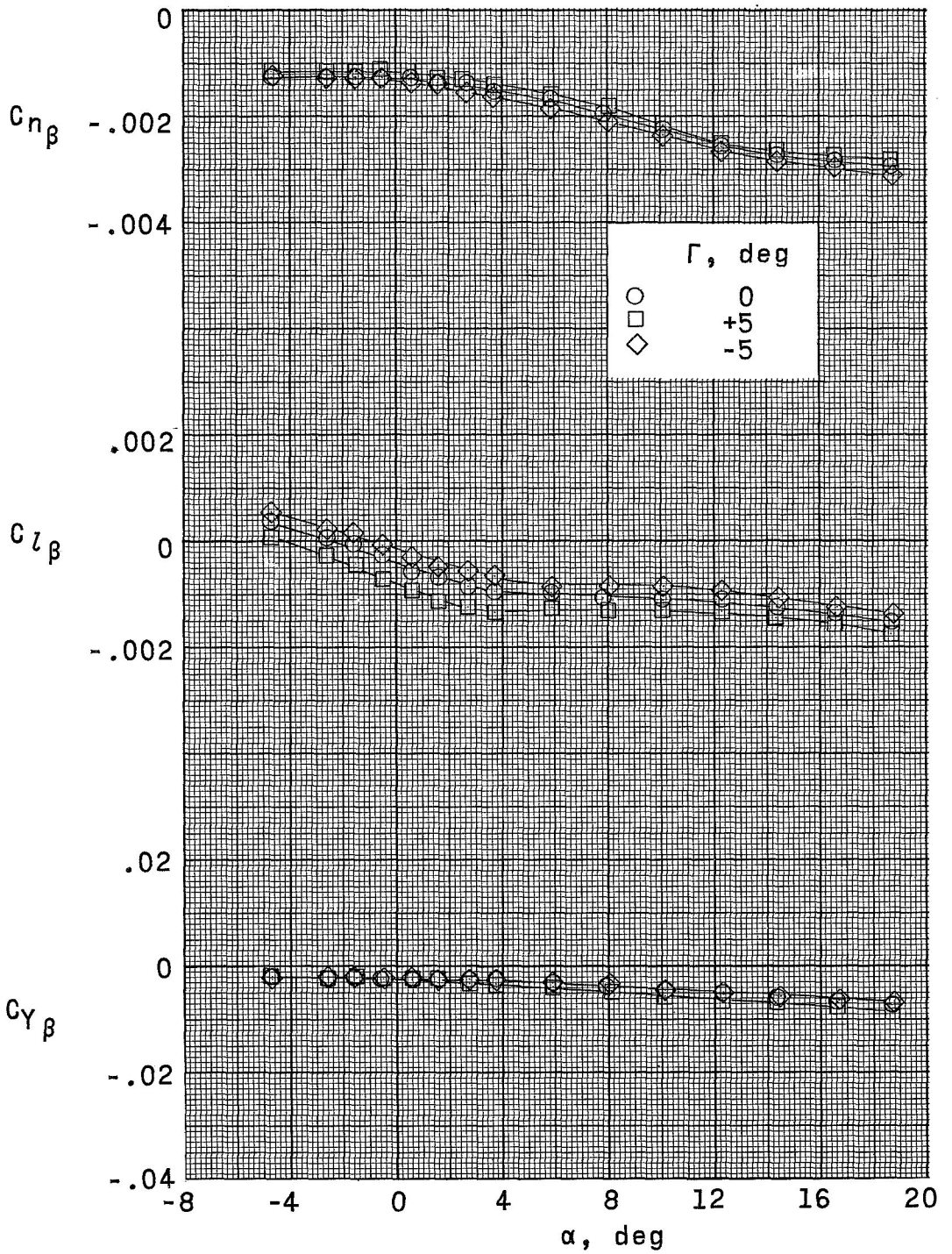
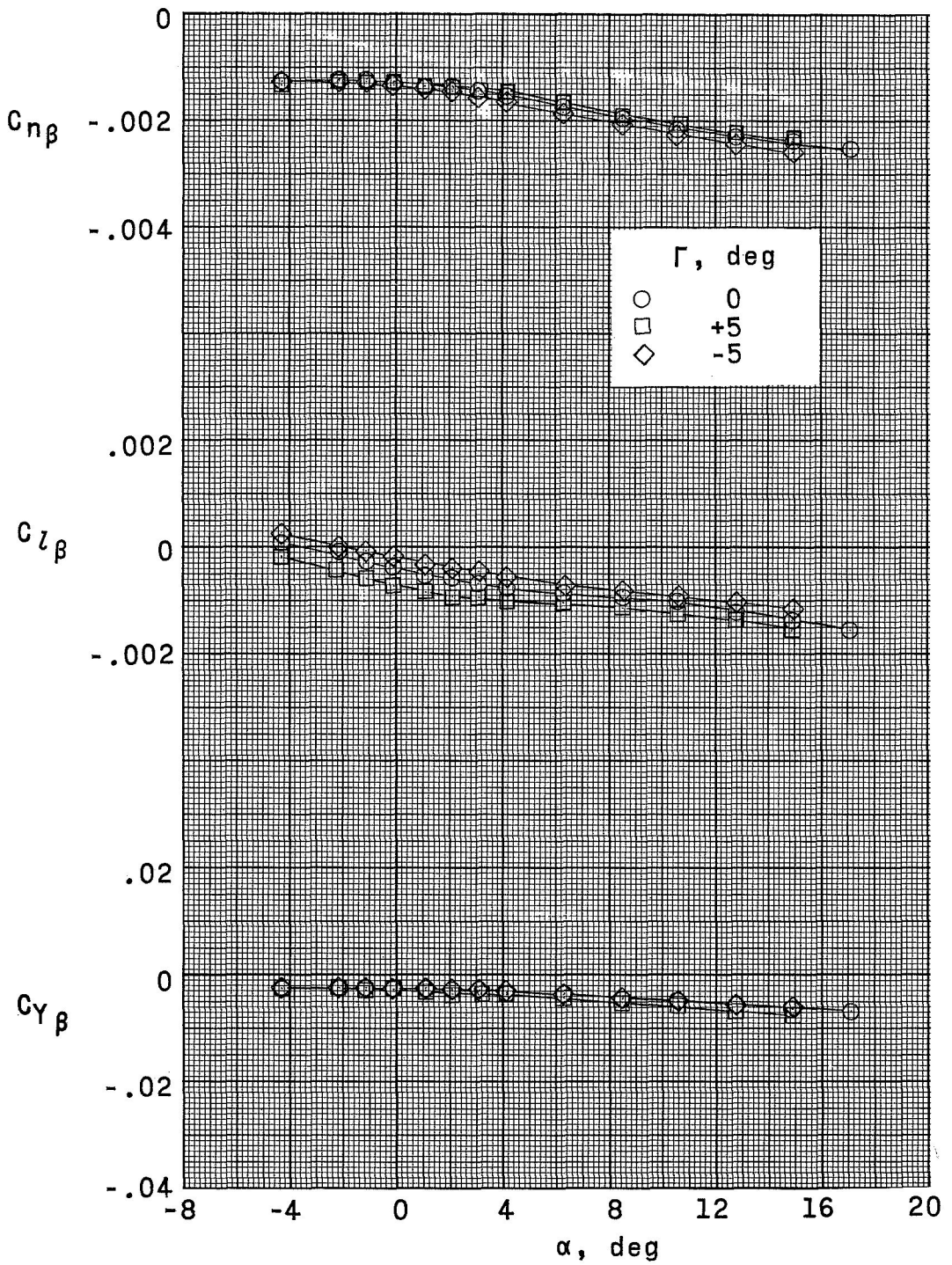


(d) M = 2.96.

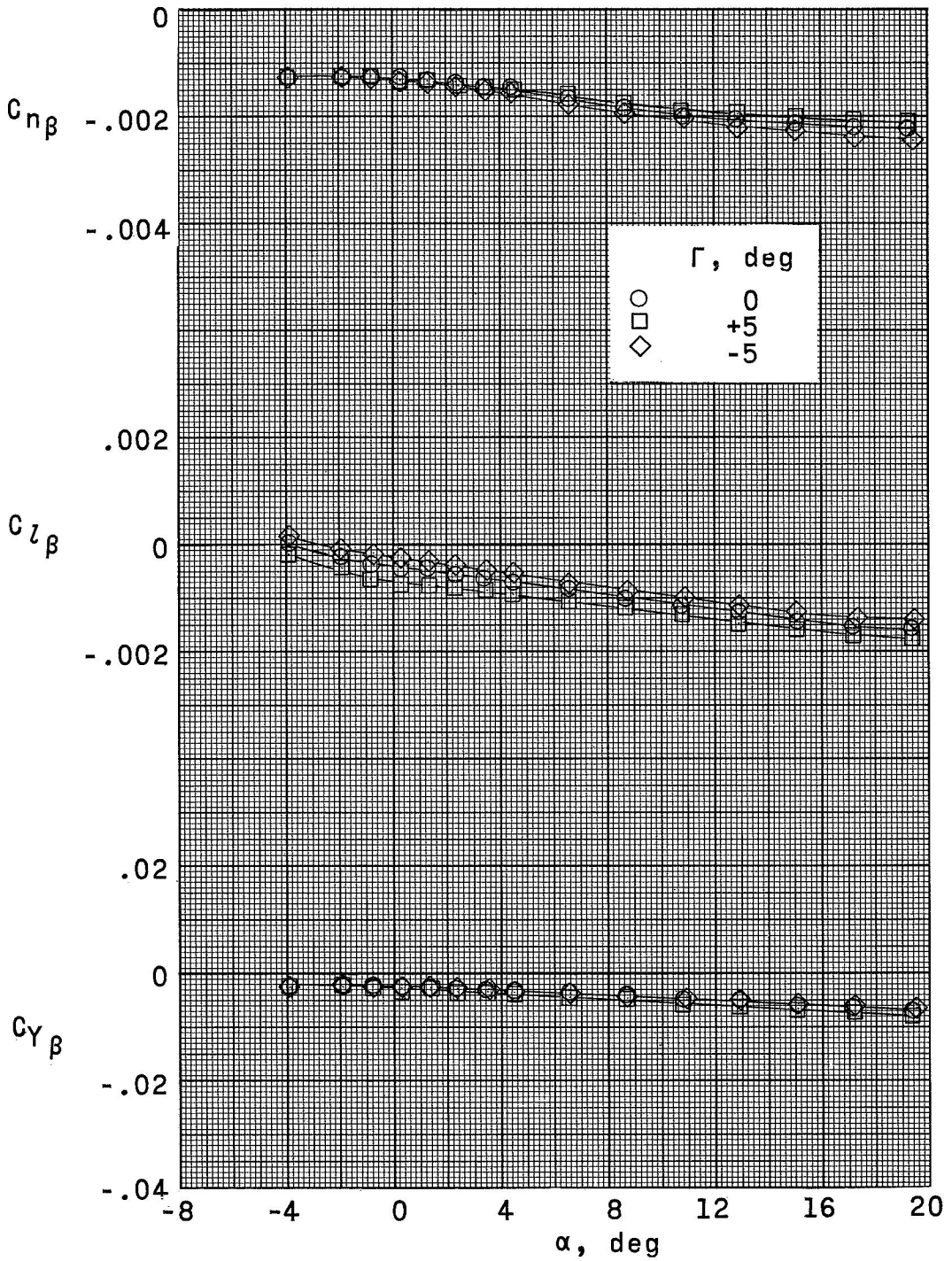
Figure 5.- Continued.



(e) M = 3.96.

Figure 5.- Continued.

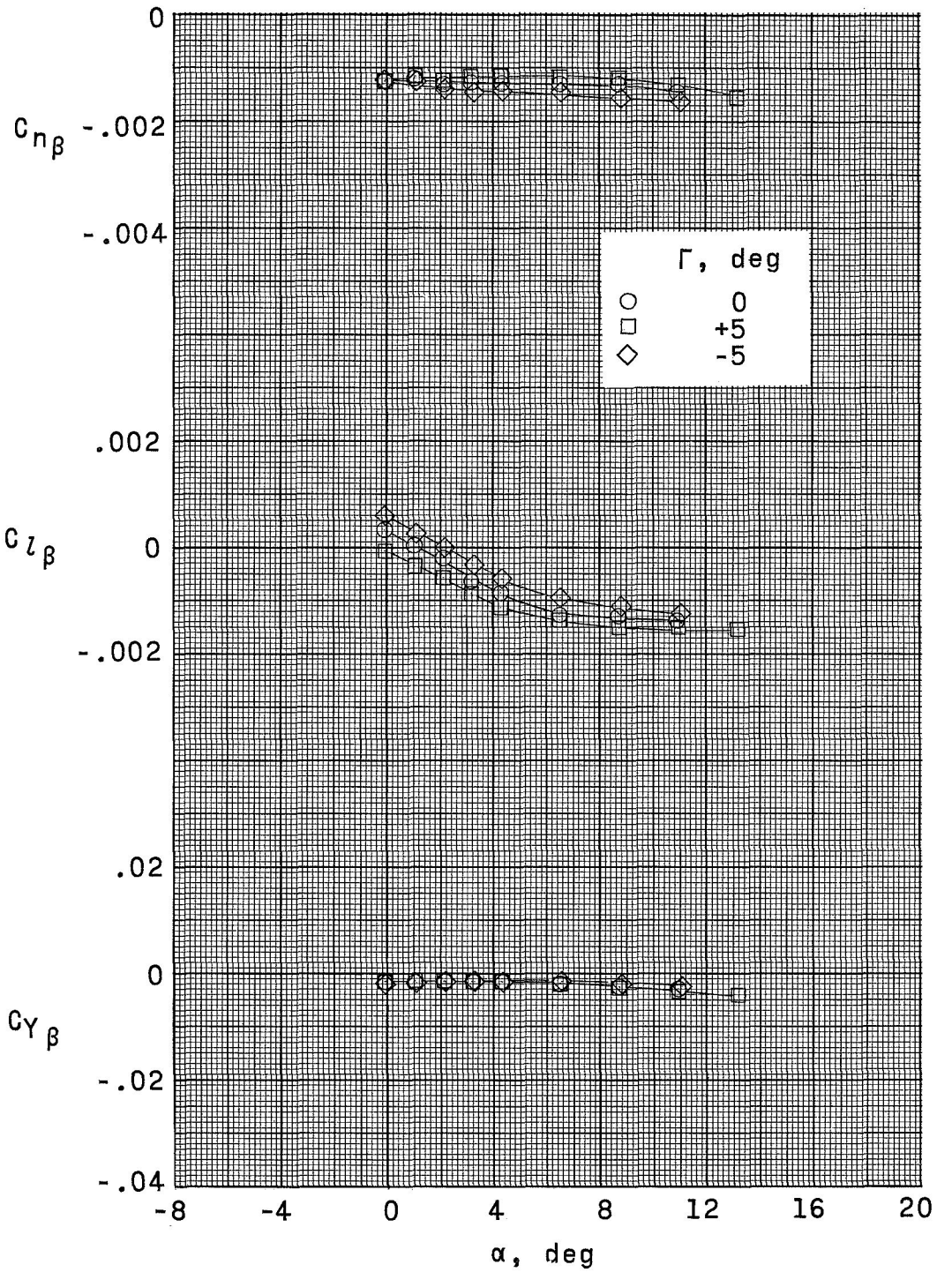
[redacted]



(f) M = 4.63.

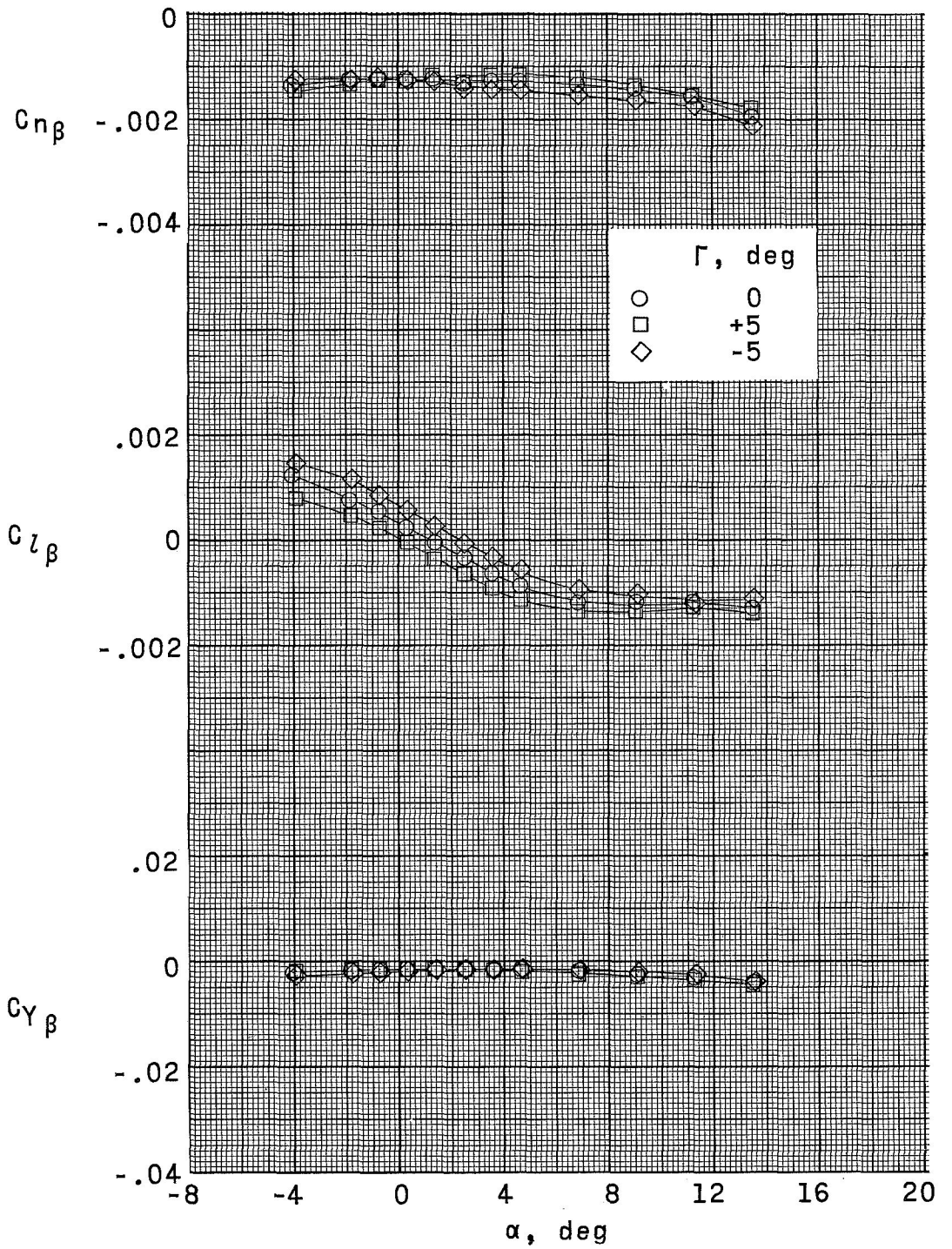
Figure 5.- Concluded.

[redacted]



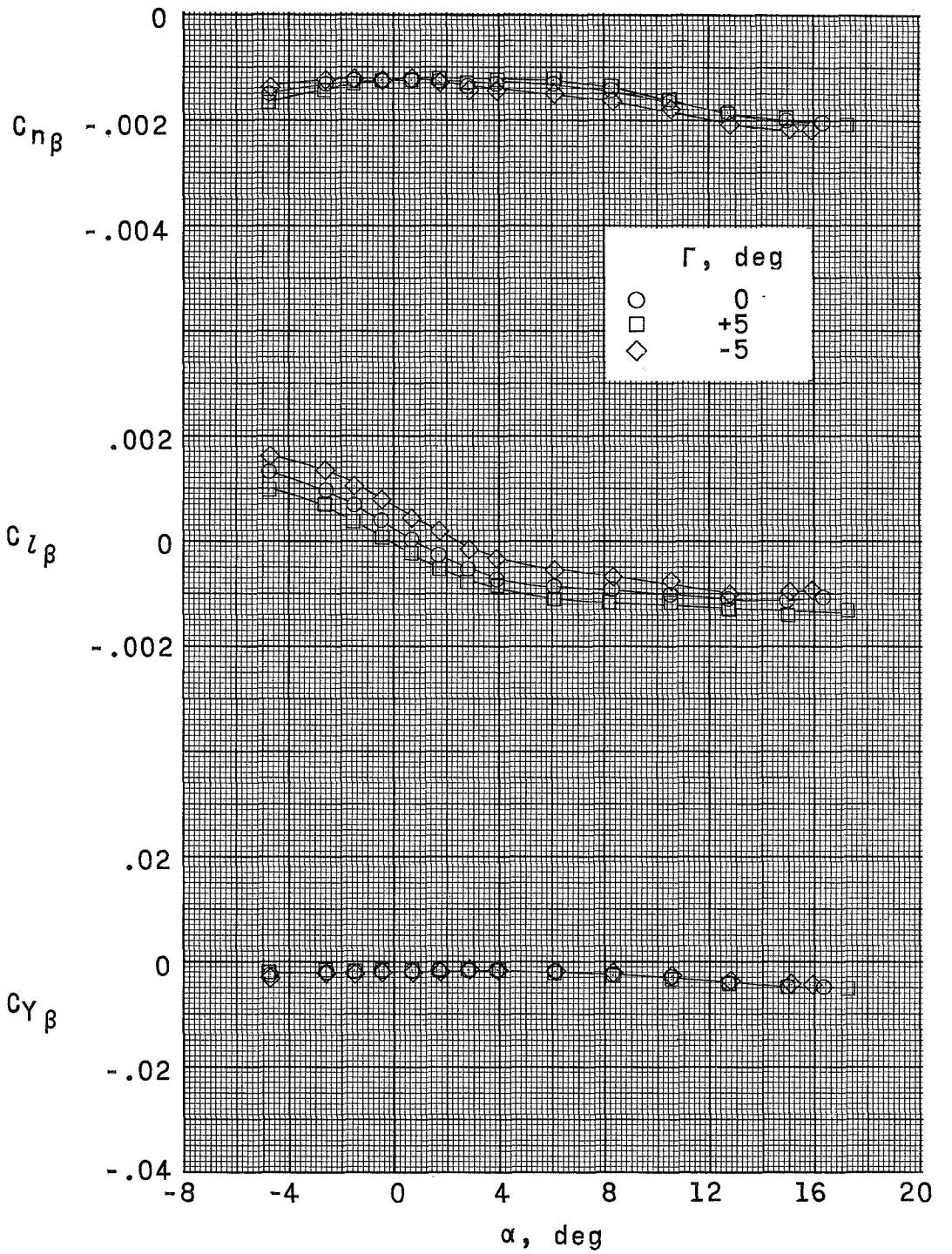
(a) M = 1.60.

Figure 6.- Effect of geometric dihedral on sideslip parameters for low-wing configuration.



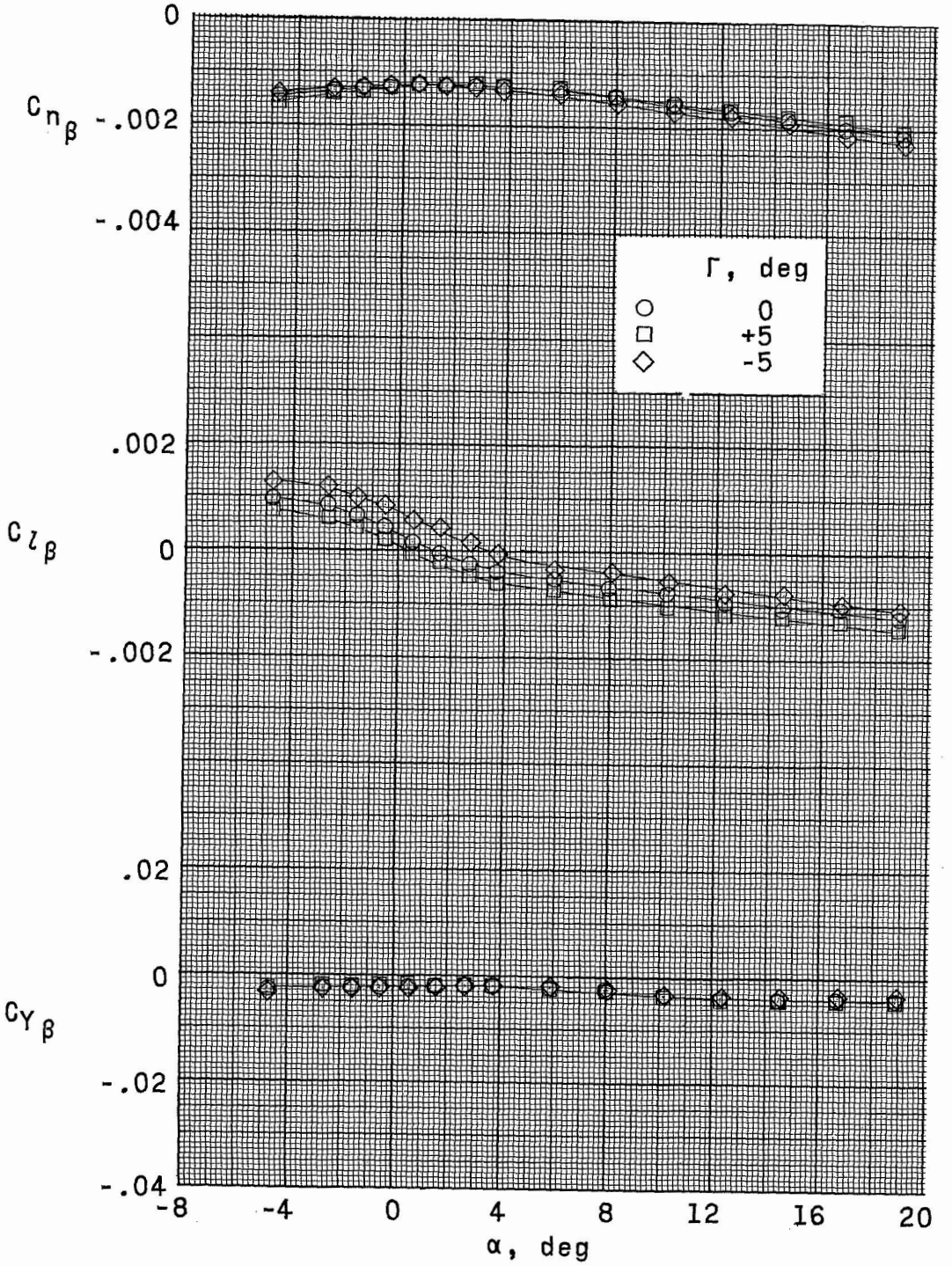
(b) M = 1.90.

Figure 6.- Continued.



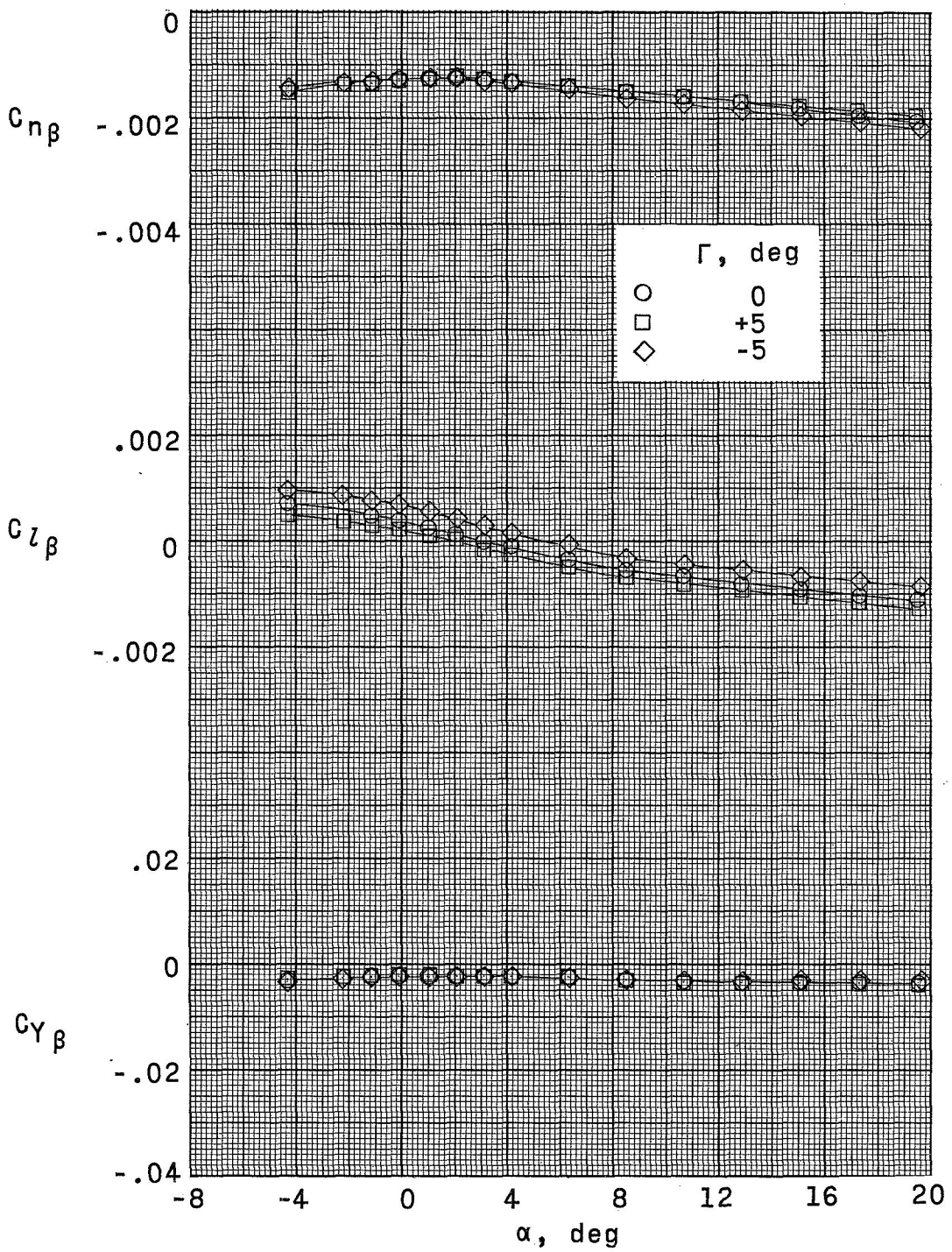
(c) M = 2.30.

Figure 6.- Continued.



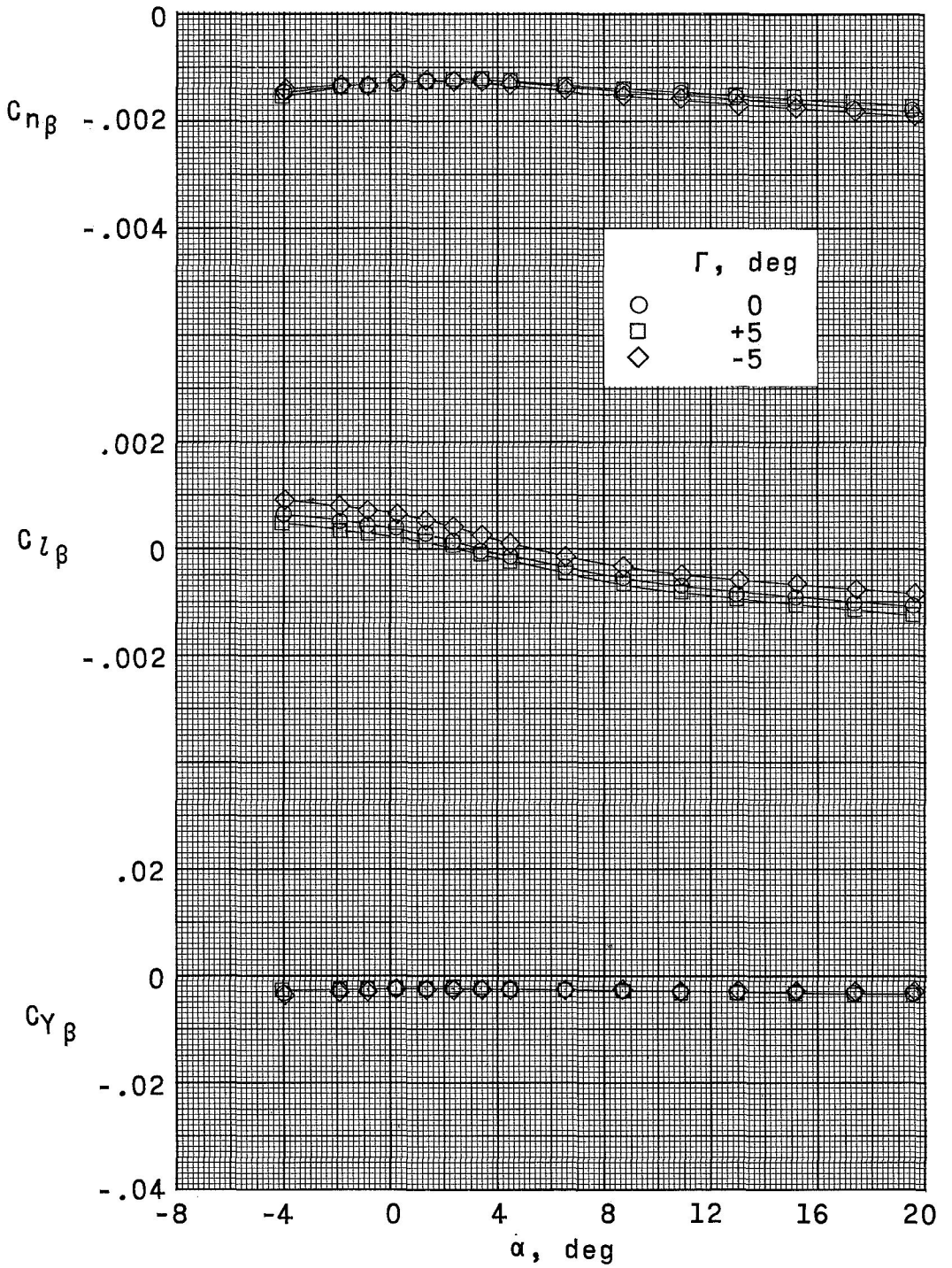
(d) M = 2.96.

Figure 6.- Continued.



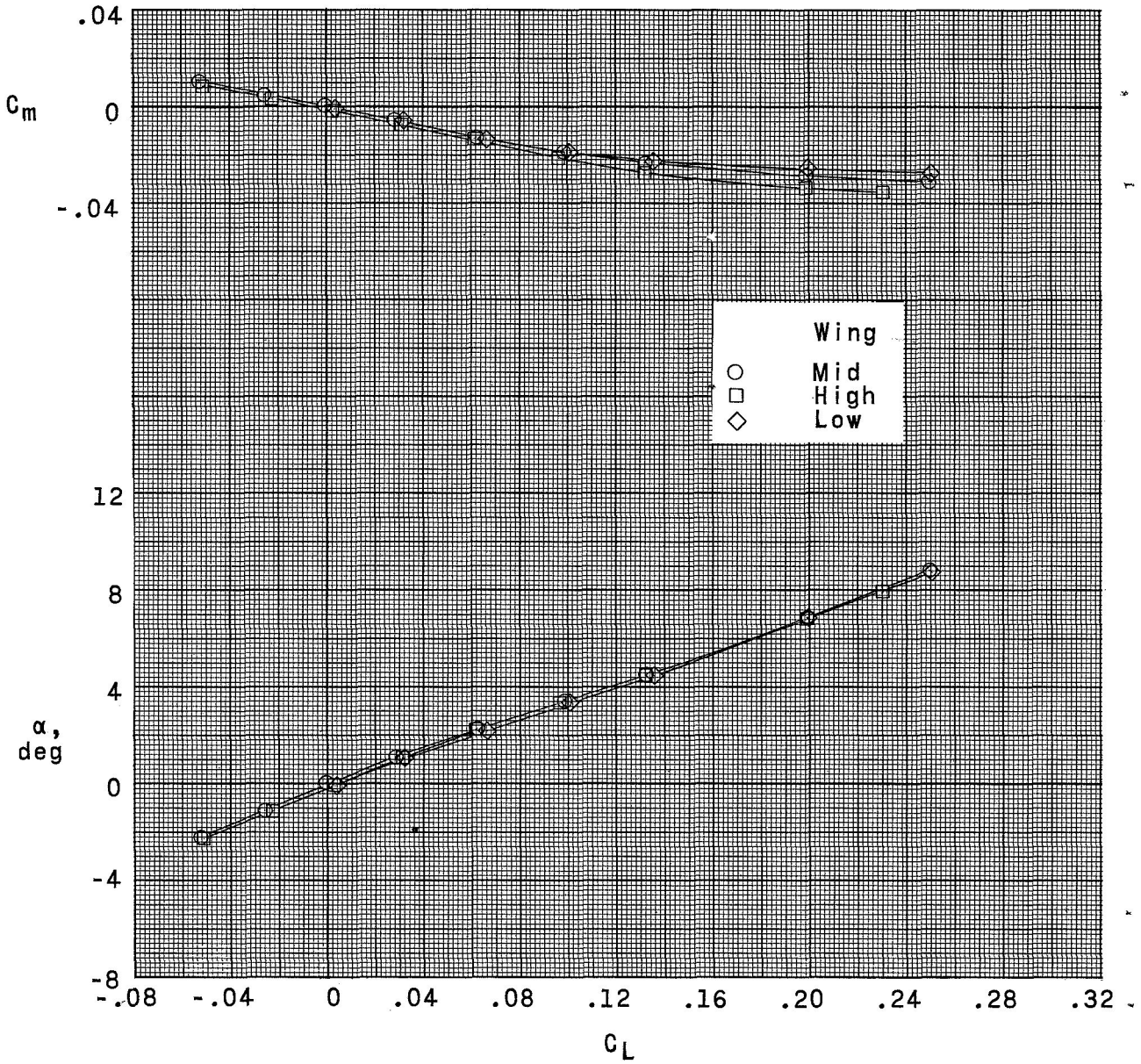
(e) M = 3.96.

Figure 6.- Continued



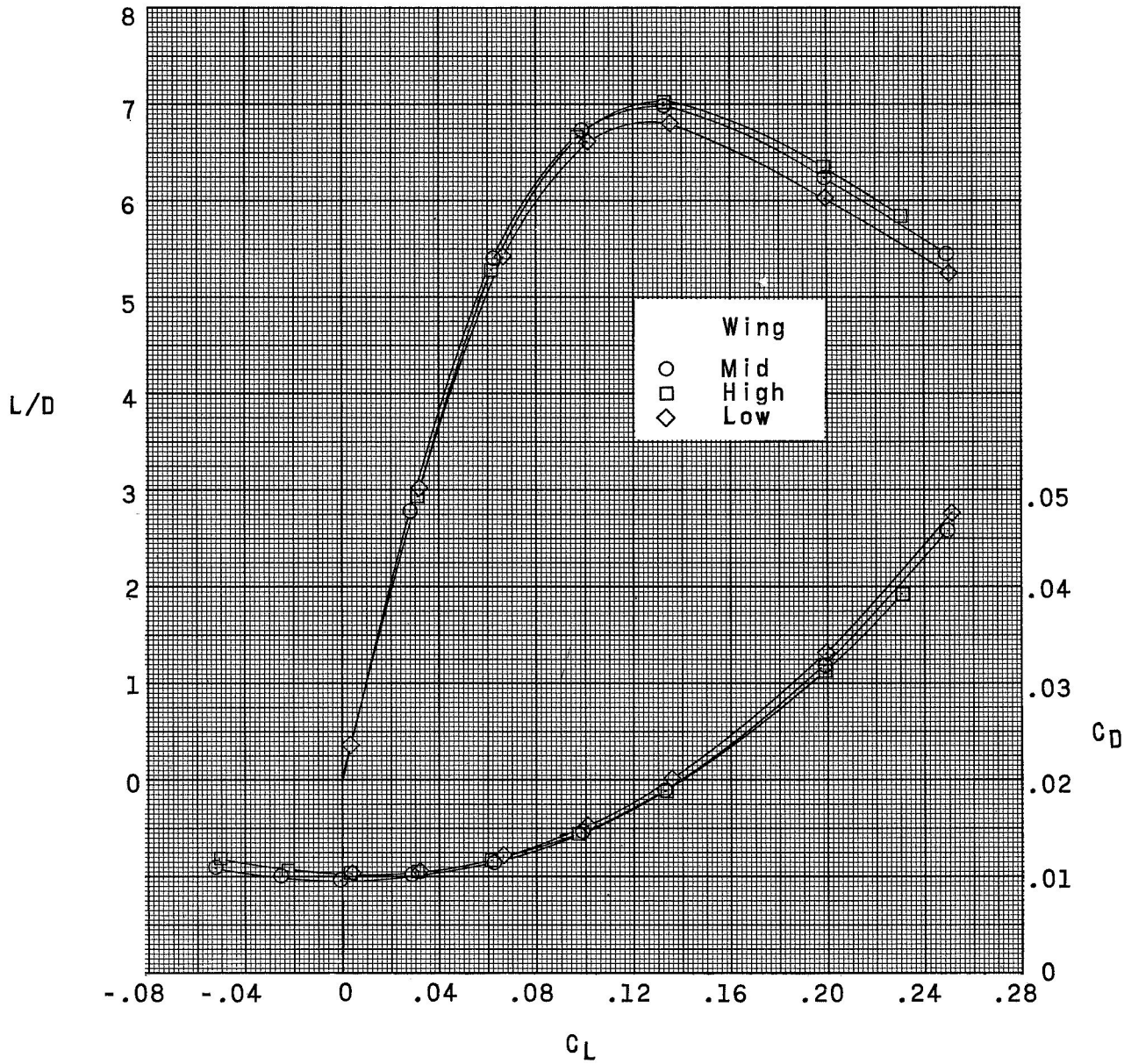
(f) M = 4.63.

Figure 6.- Concluded.



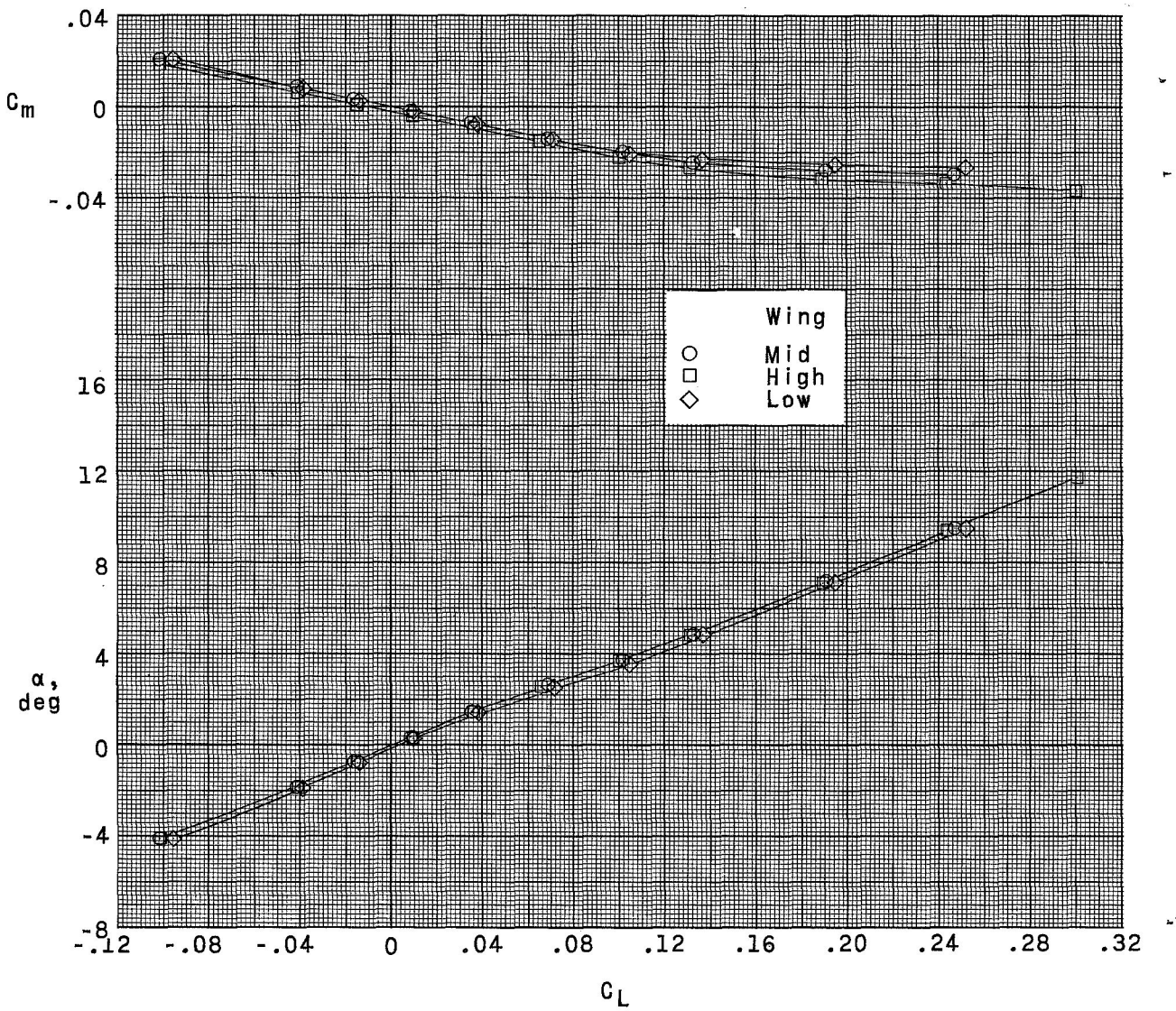
(a) M = 1.60.

Figure 7.- Effect of wing height on aerodynamic characteristics in pitch.



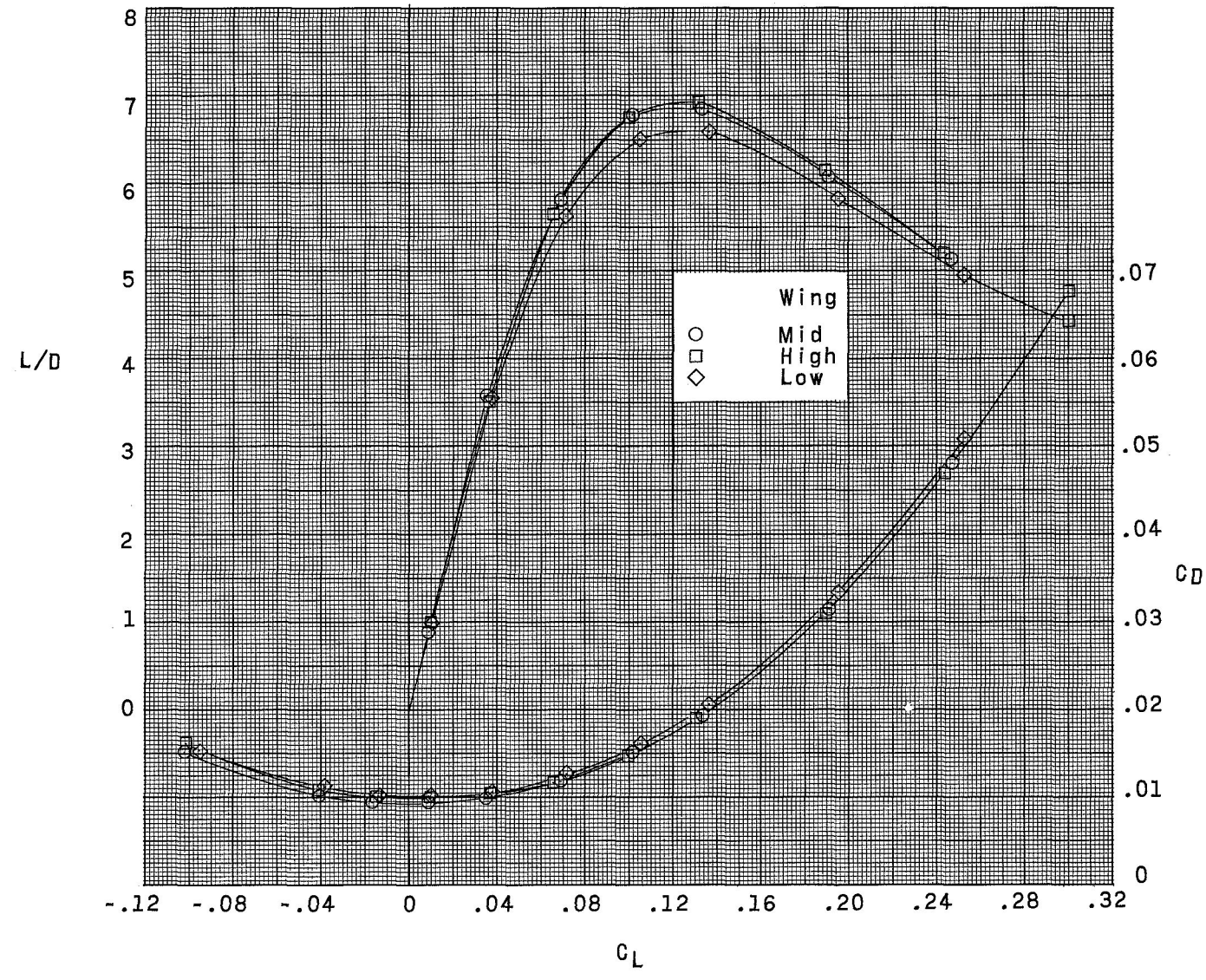
(a) Concluded.

Figure 7.- Continued.



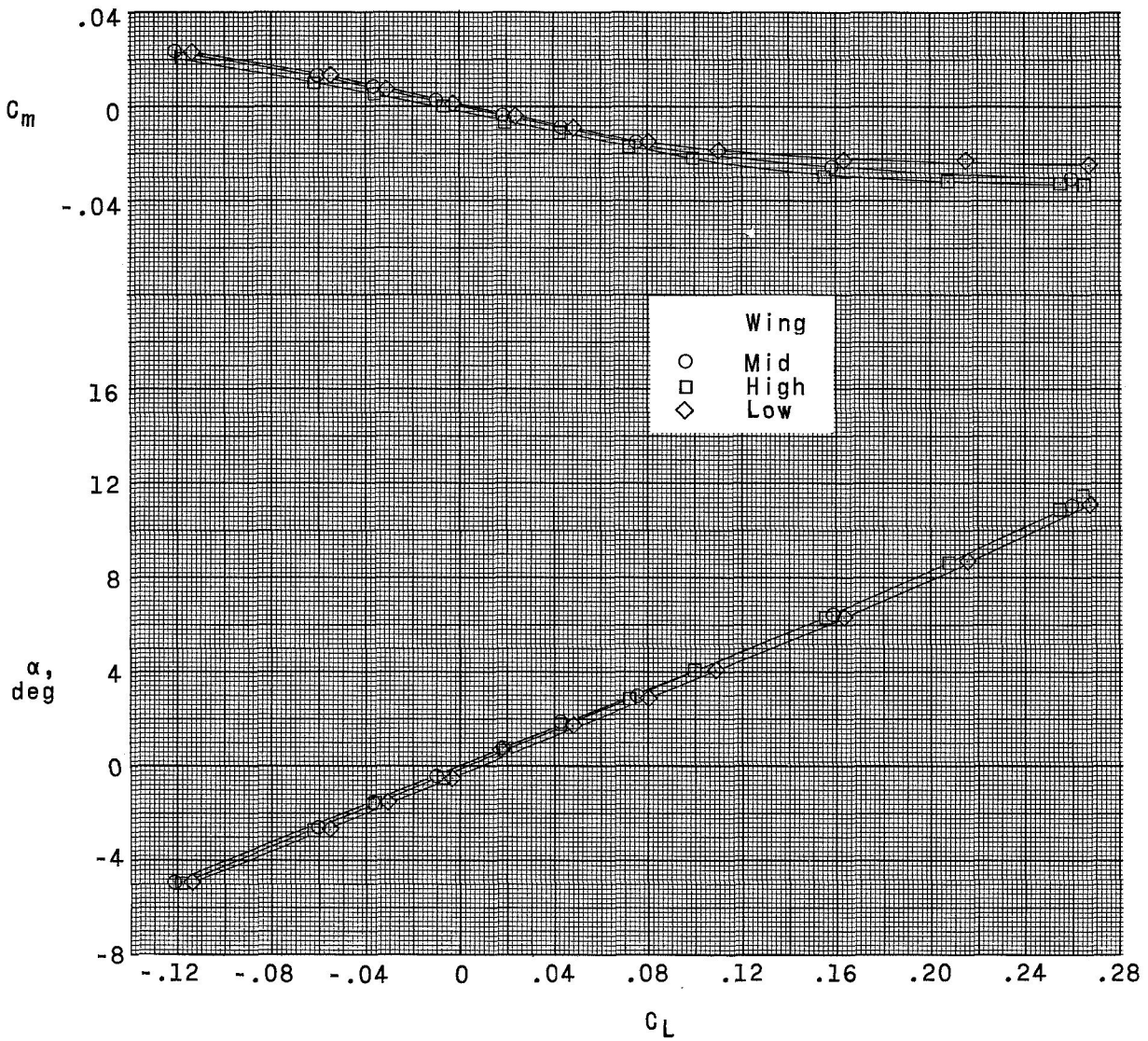
(b) M = 1.90.

Figure 7.- Continued.



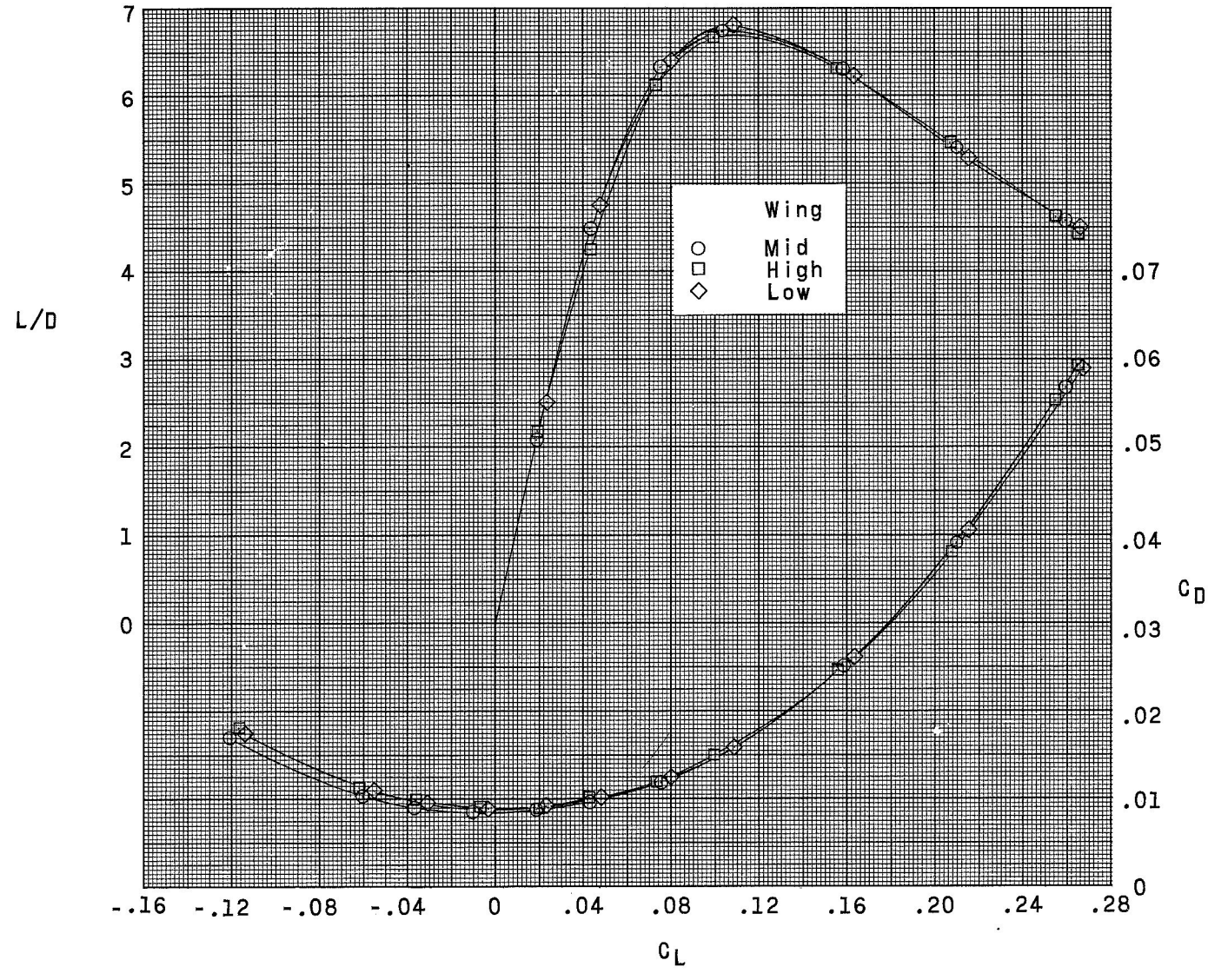
(b) Concluded.

Figure 7.- Continued.



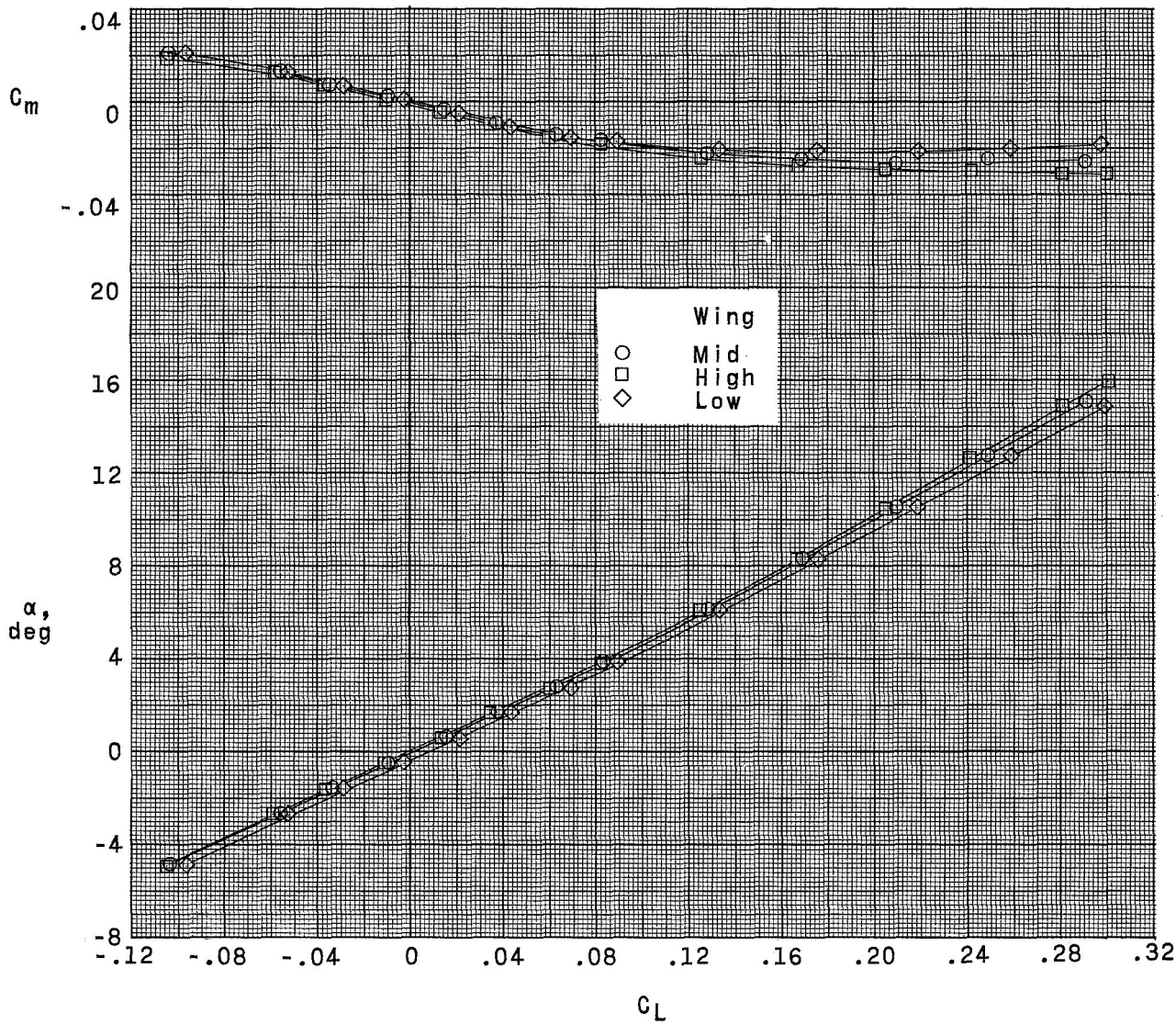
(c) M = 2.30.

Figure 7.- Continued.



(c) Concluded.

Figure 7.- Continued.



(d) M = 2.96.

Figure 7.- Continued.

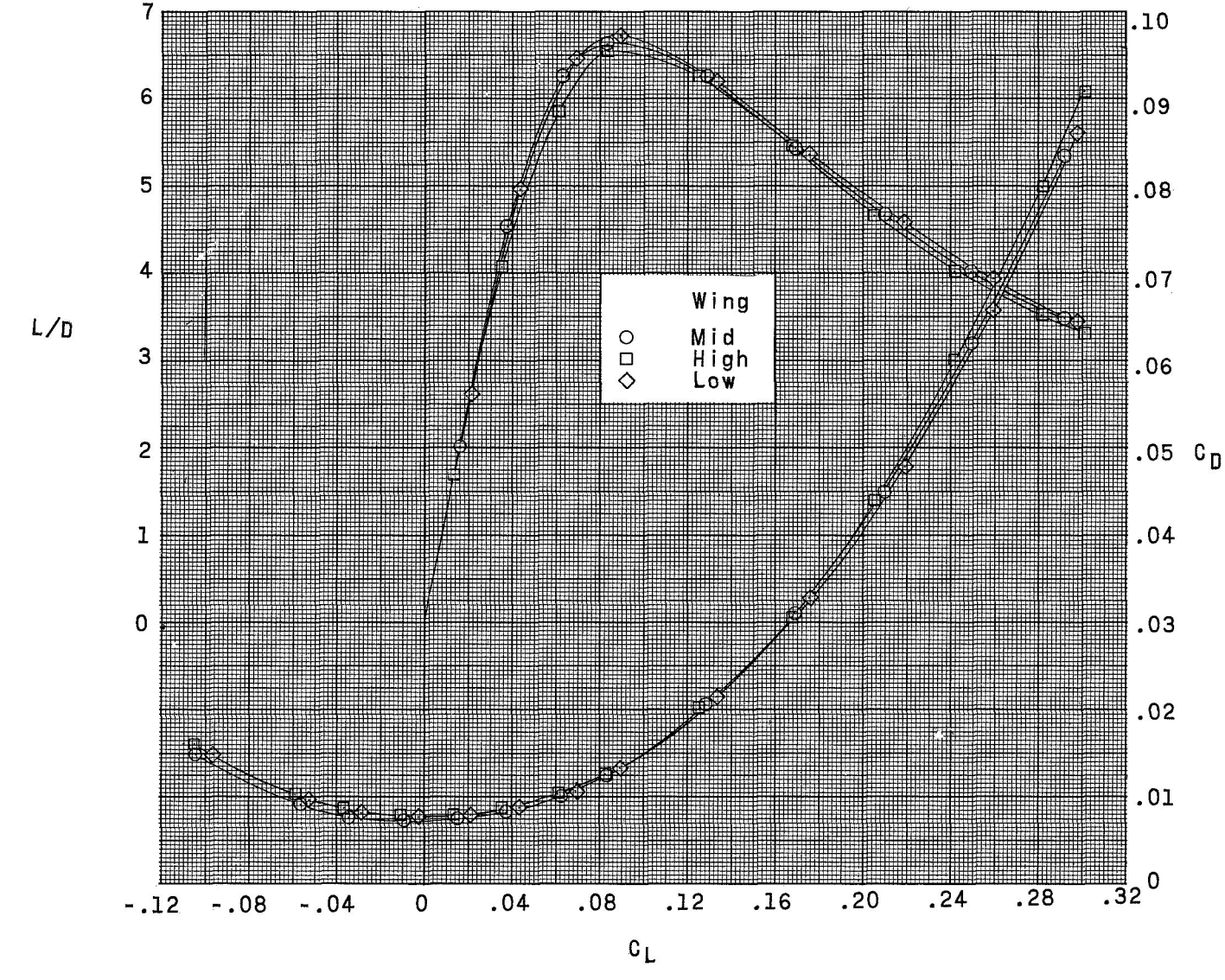


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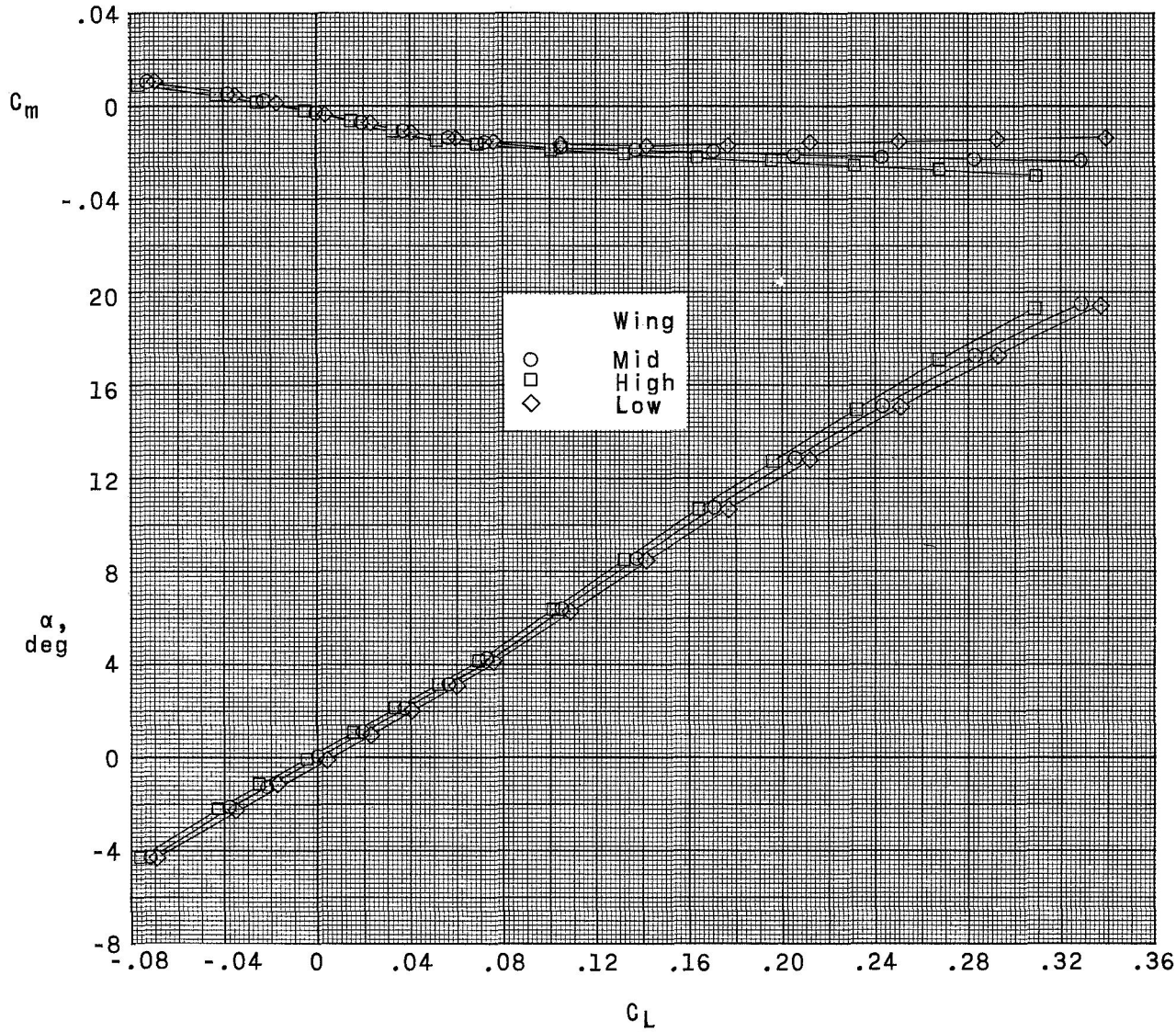
Figure 7.- Continued.



(e) M = 3.96.

Figure 7.- Continued.

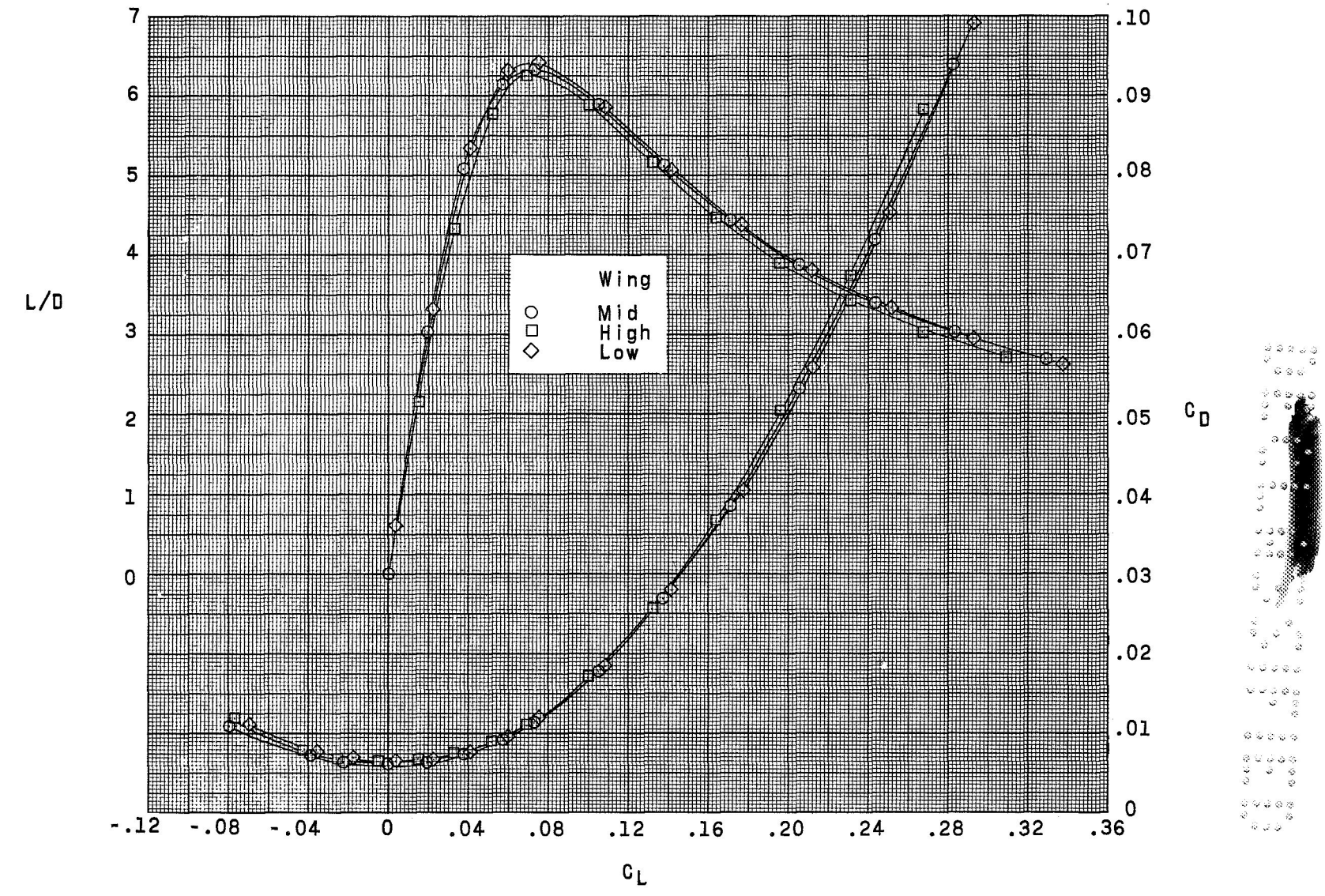


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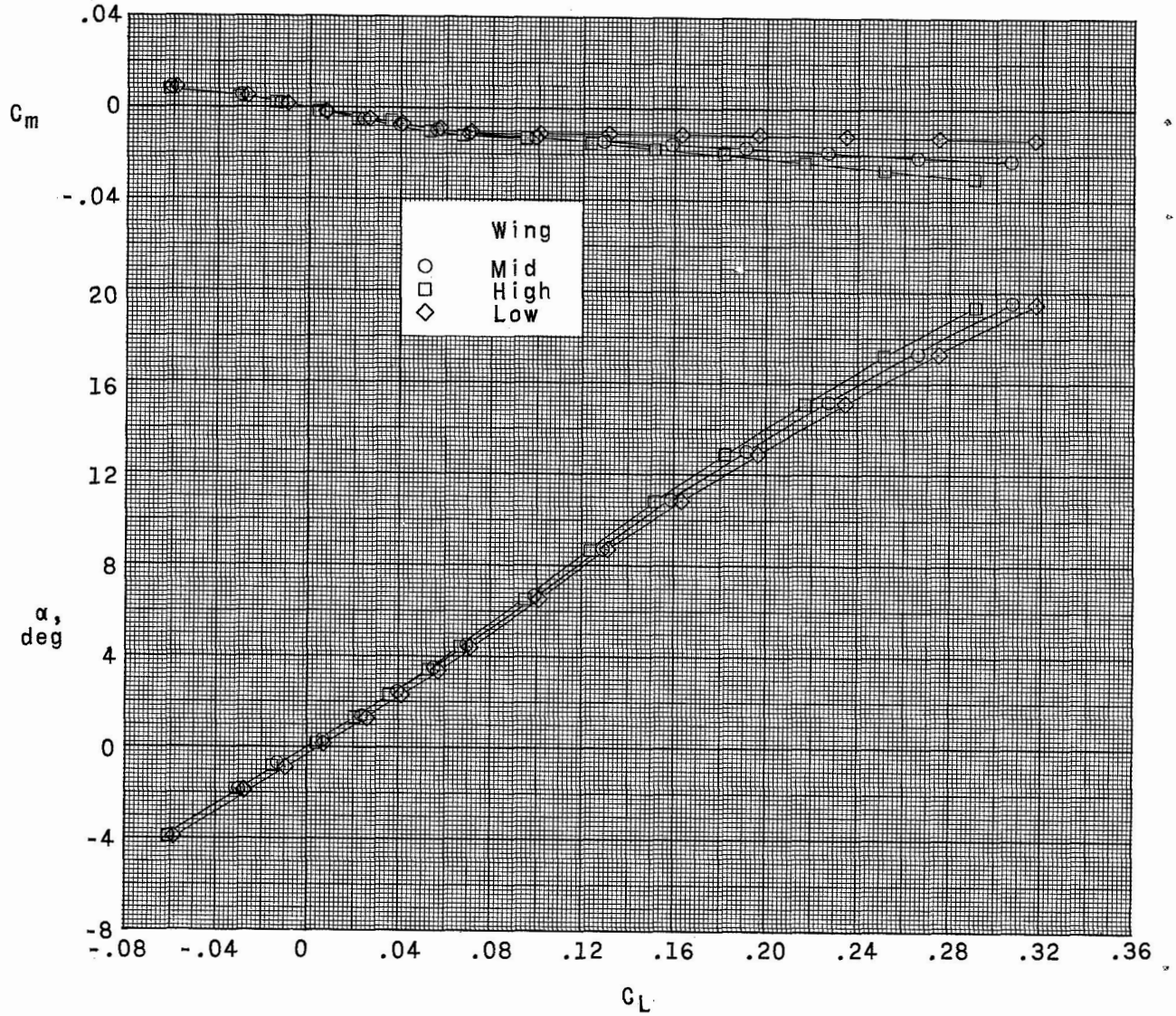
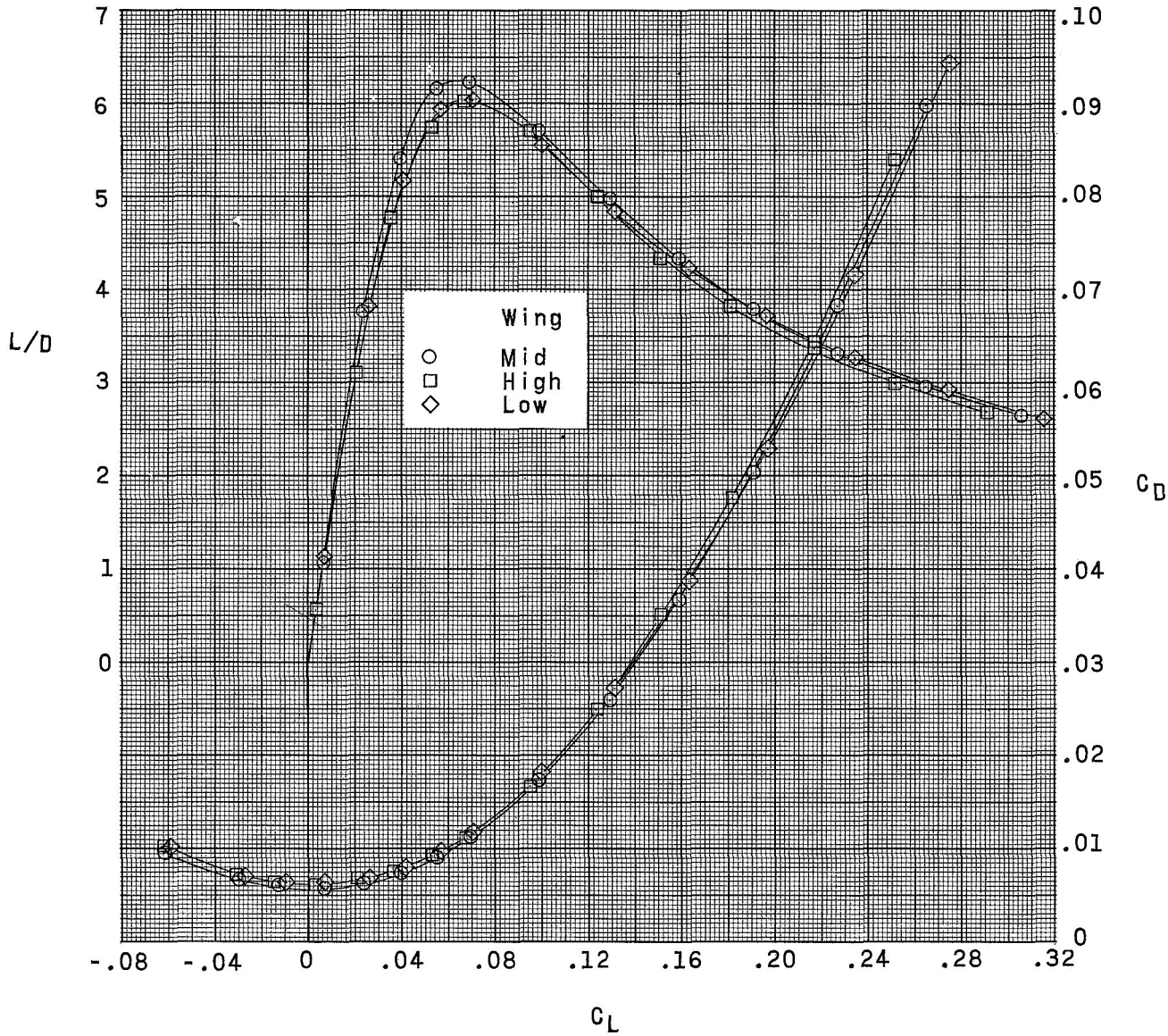
Figure 7.- Continued.



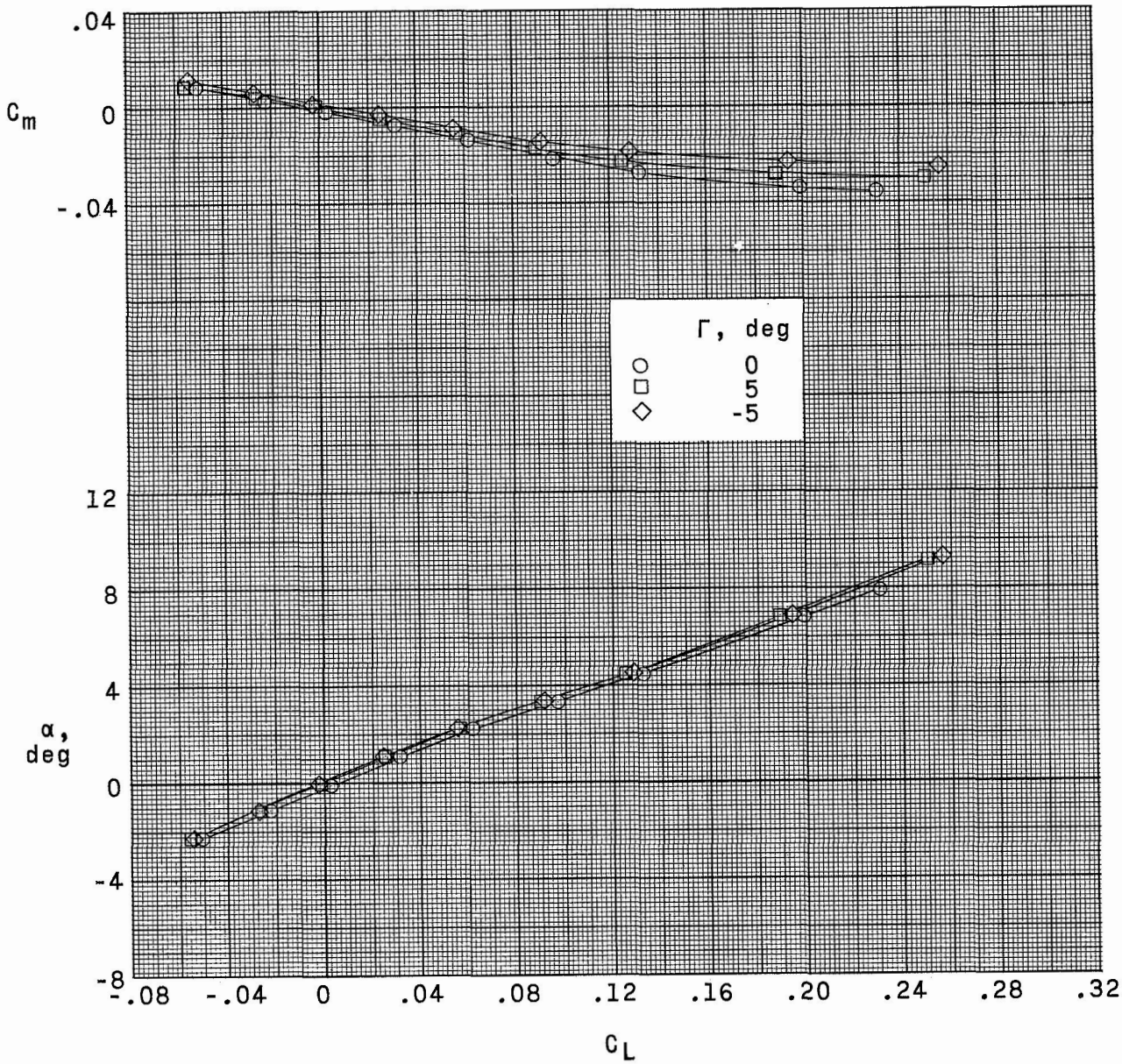
(f) M = 4.63.

Figure 7.- Continued.



(f) Concluded.

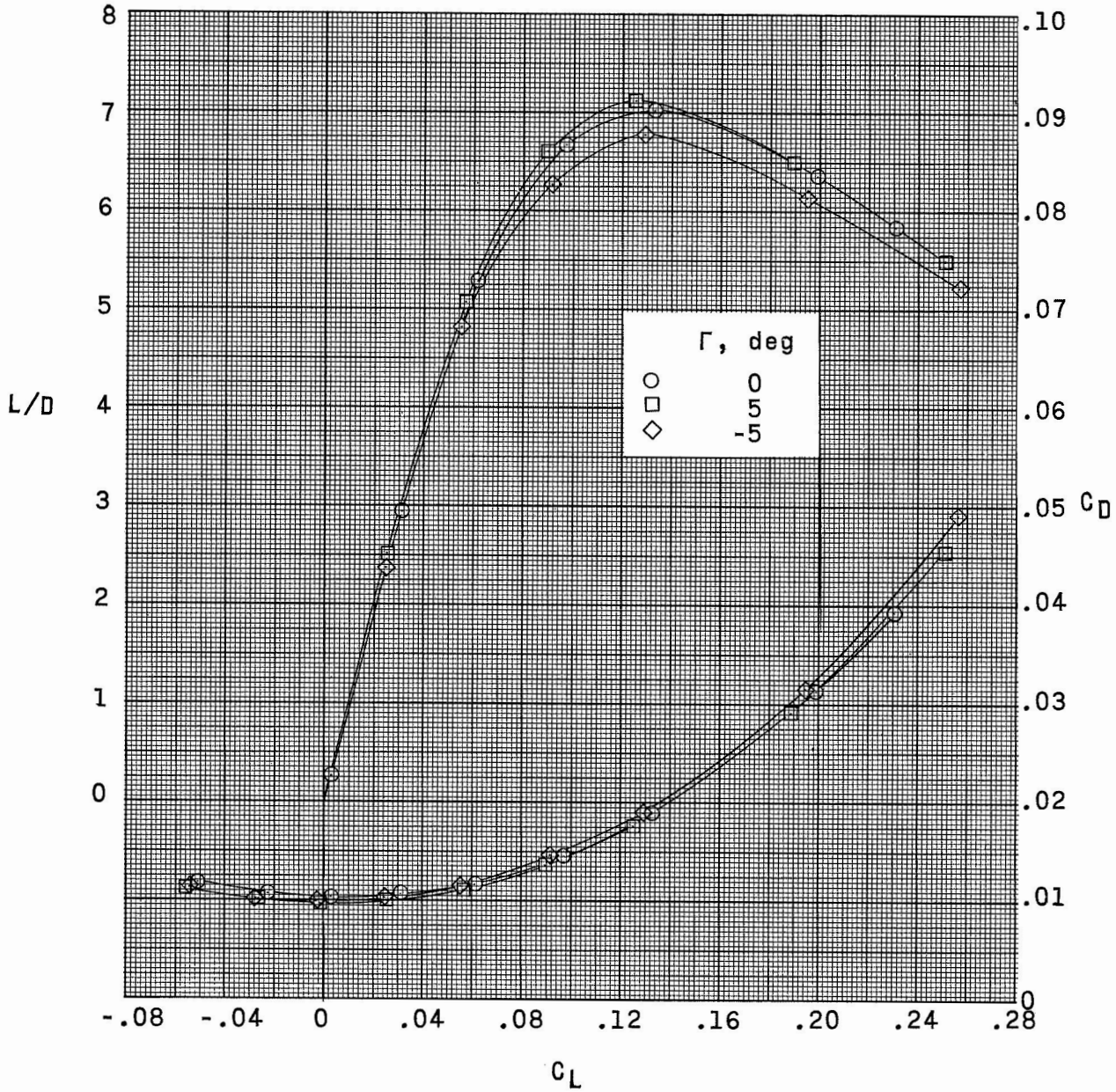
Figure 7.- Concluded.



(a) M = 1.60.

Figure 8.- Effect of geometric dihedral on aerodynamic characteristics in pitch for high-wing configuration.

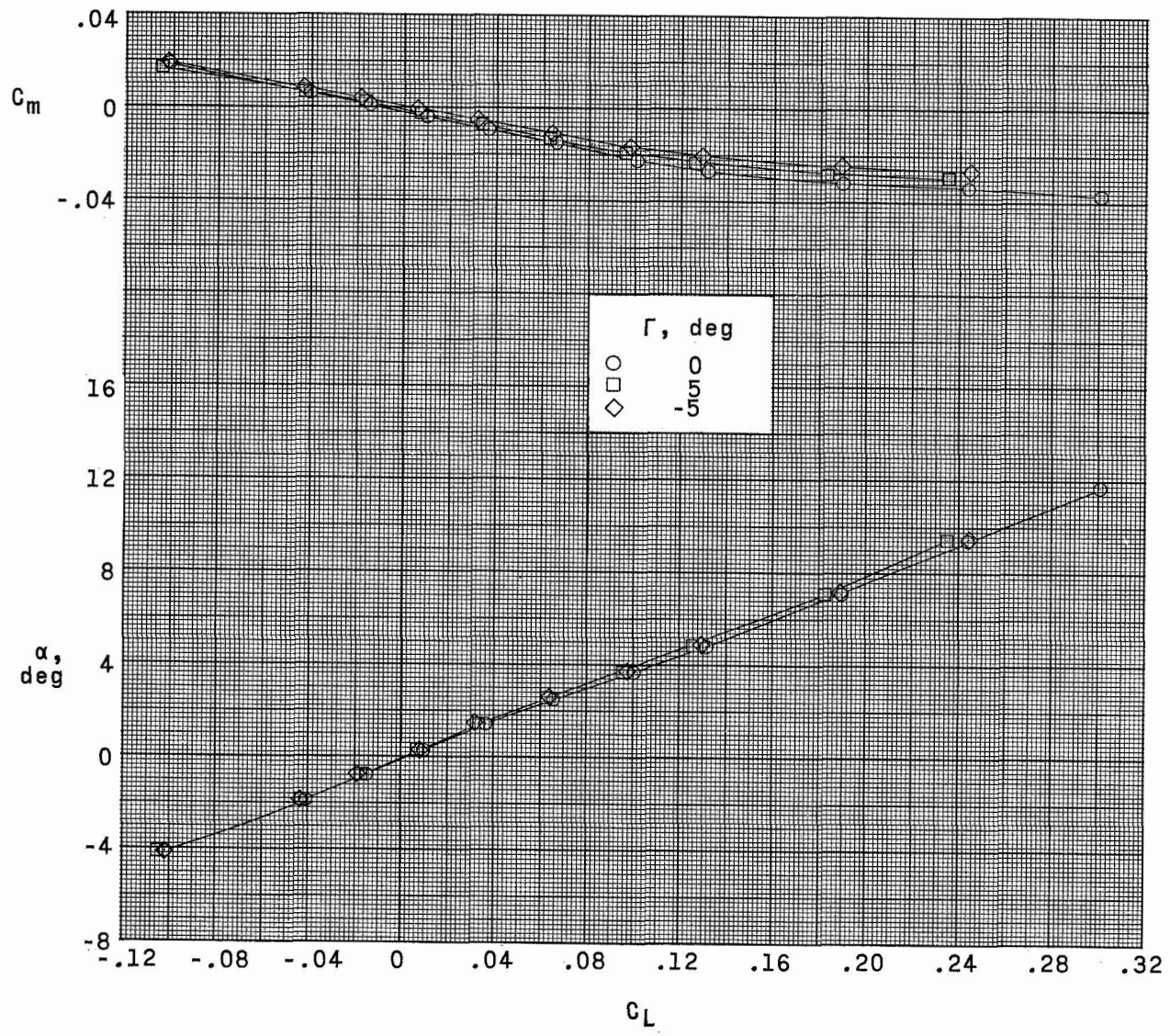
[redacted]



(a) Concluded.

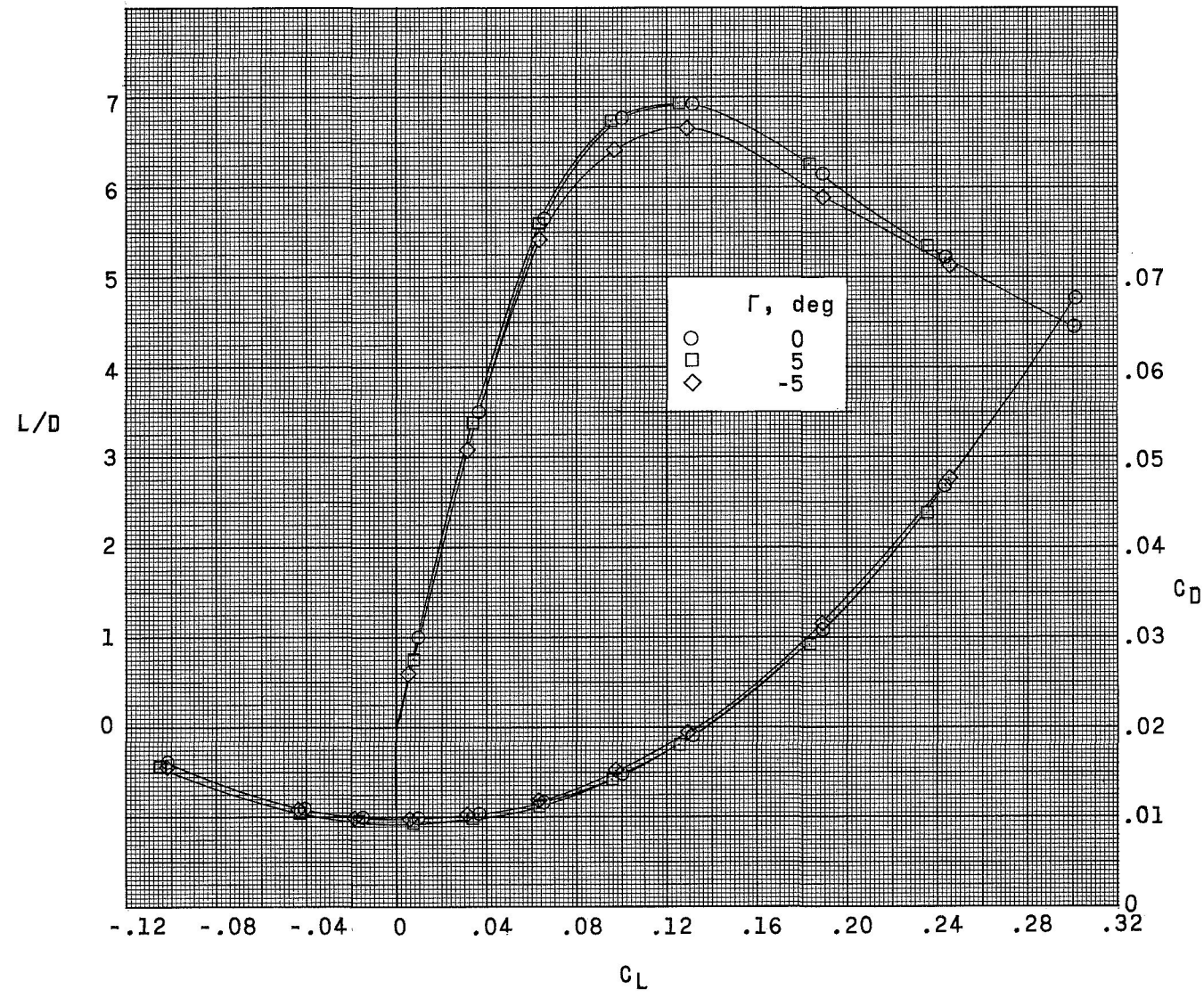
Figure 8.- Continued.

[redacted]



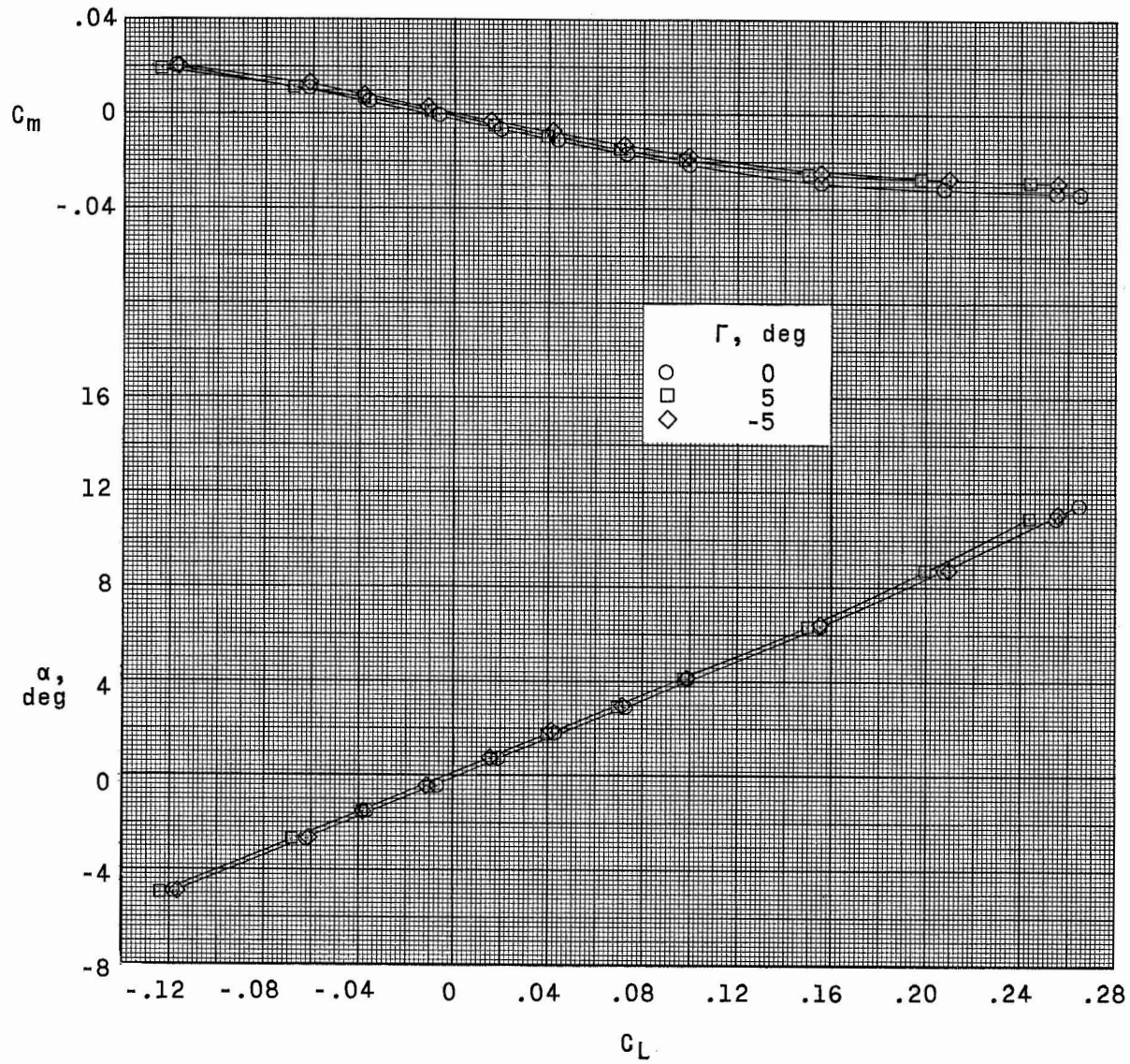
(b) M = 1.90.

Figure 8.- Continued.



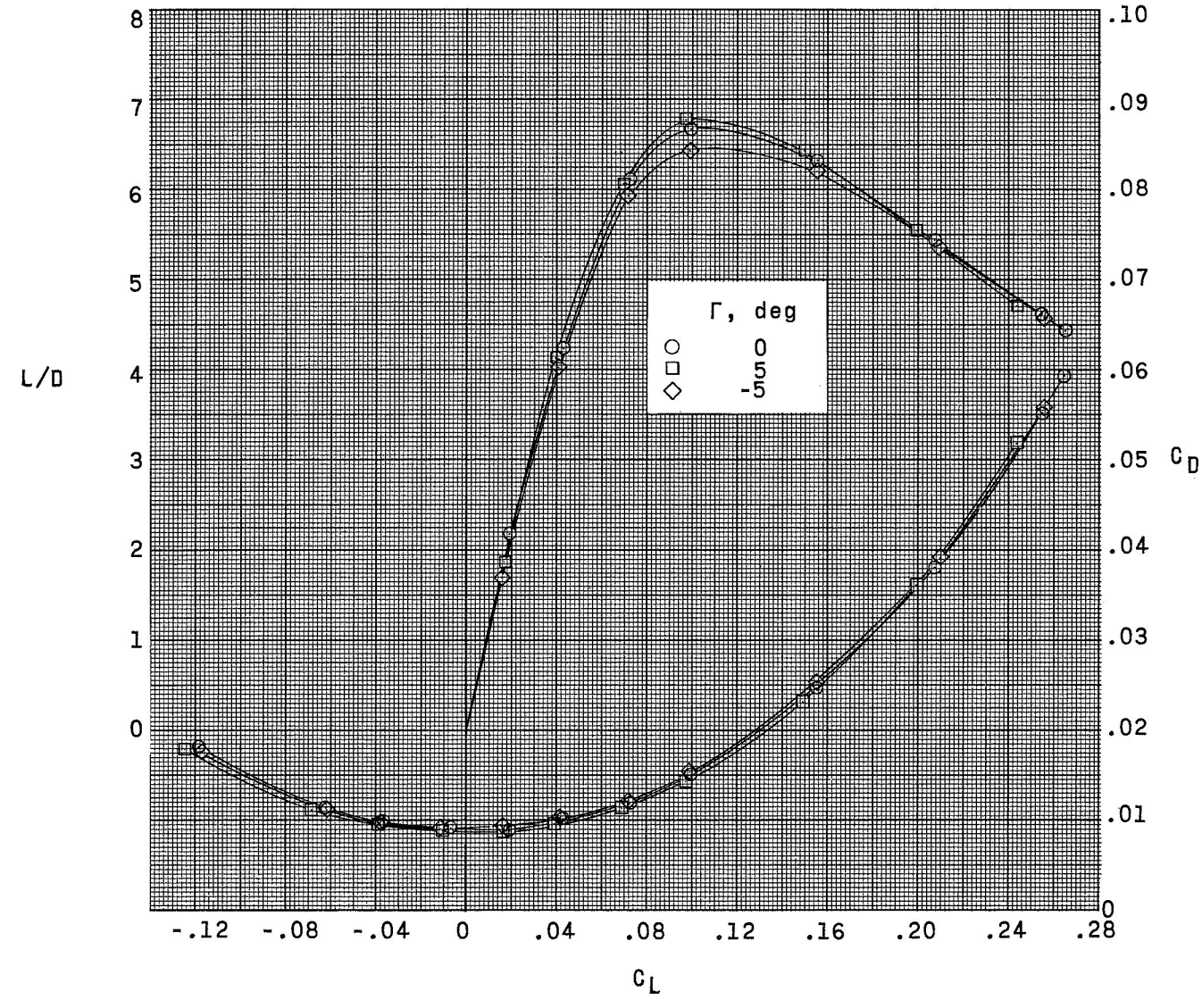
(b) Concluded.

Figure 8.- Continued.



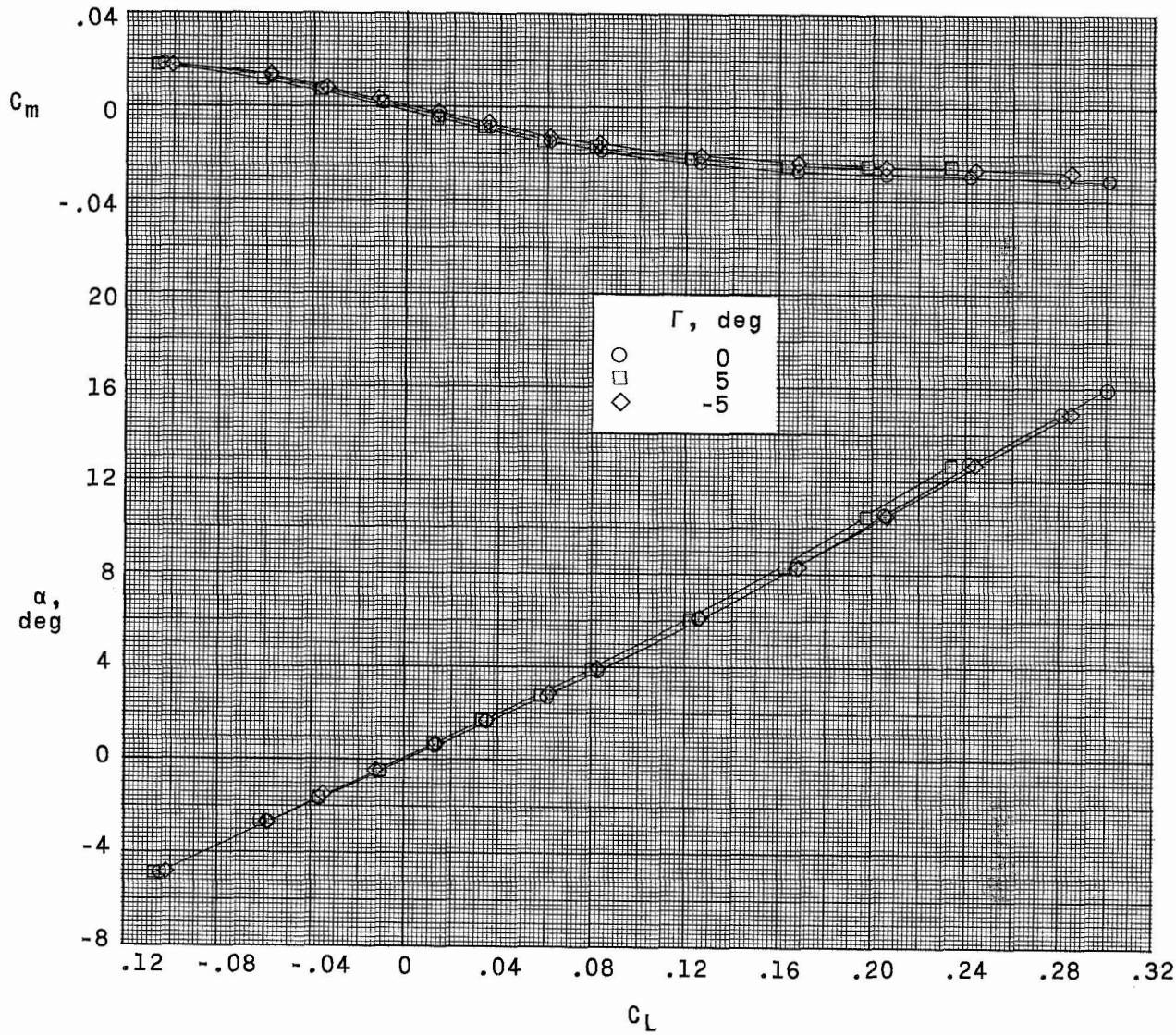
(c) M = 2.30.

Figure 8.- Continued.



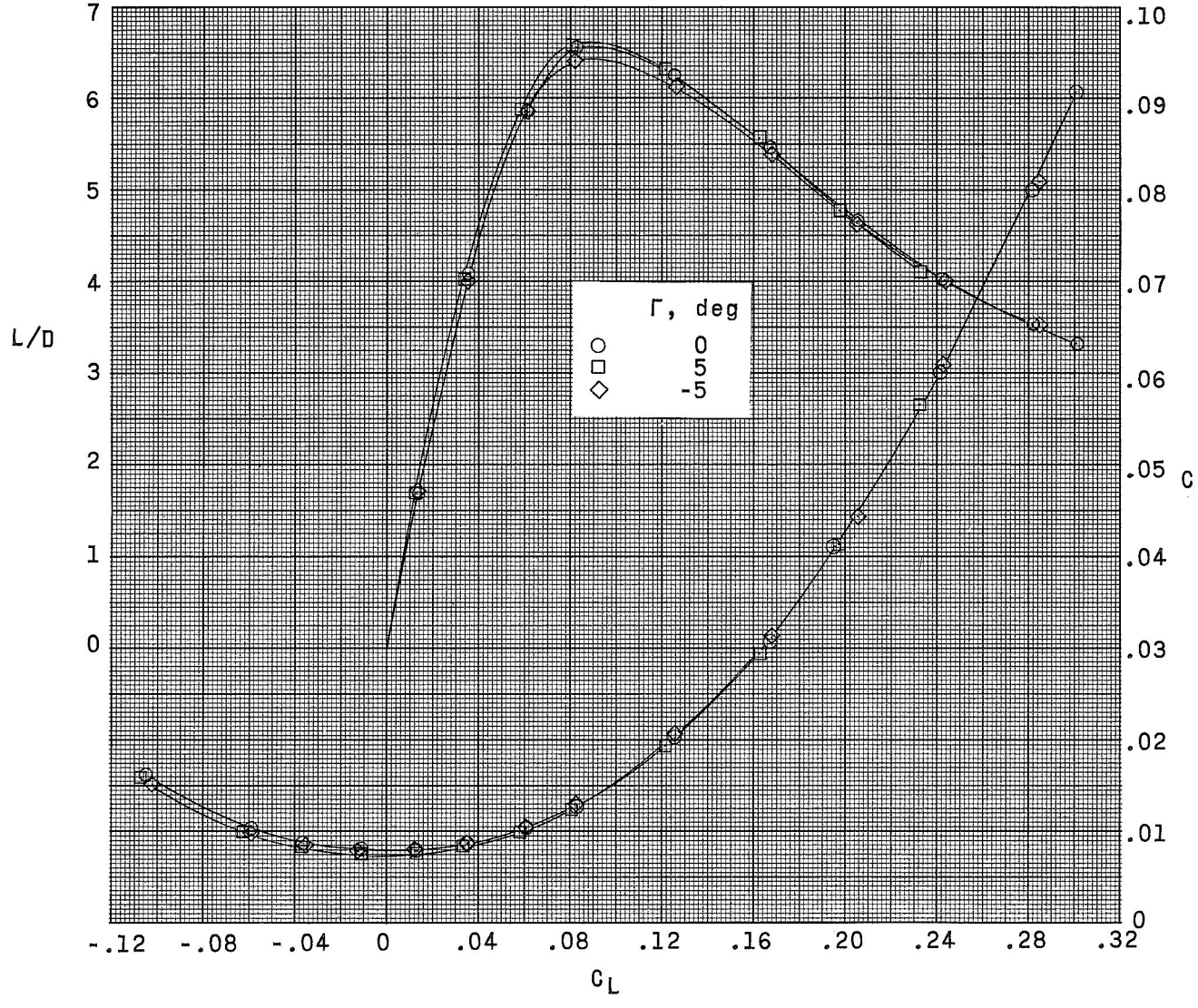
(c) Concluded.

Figure 8.- Continued.



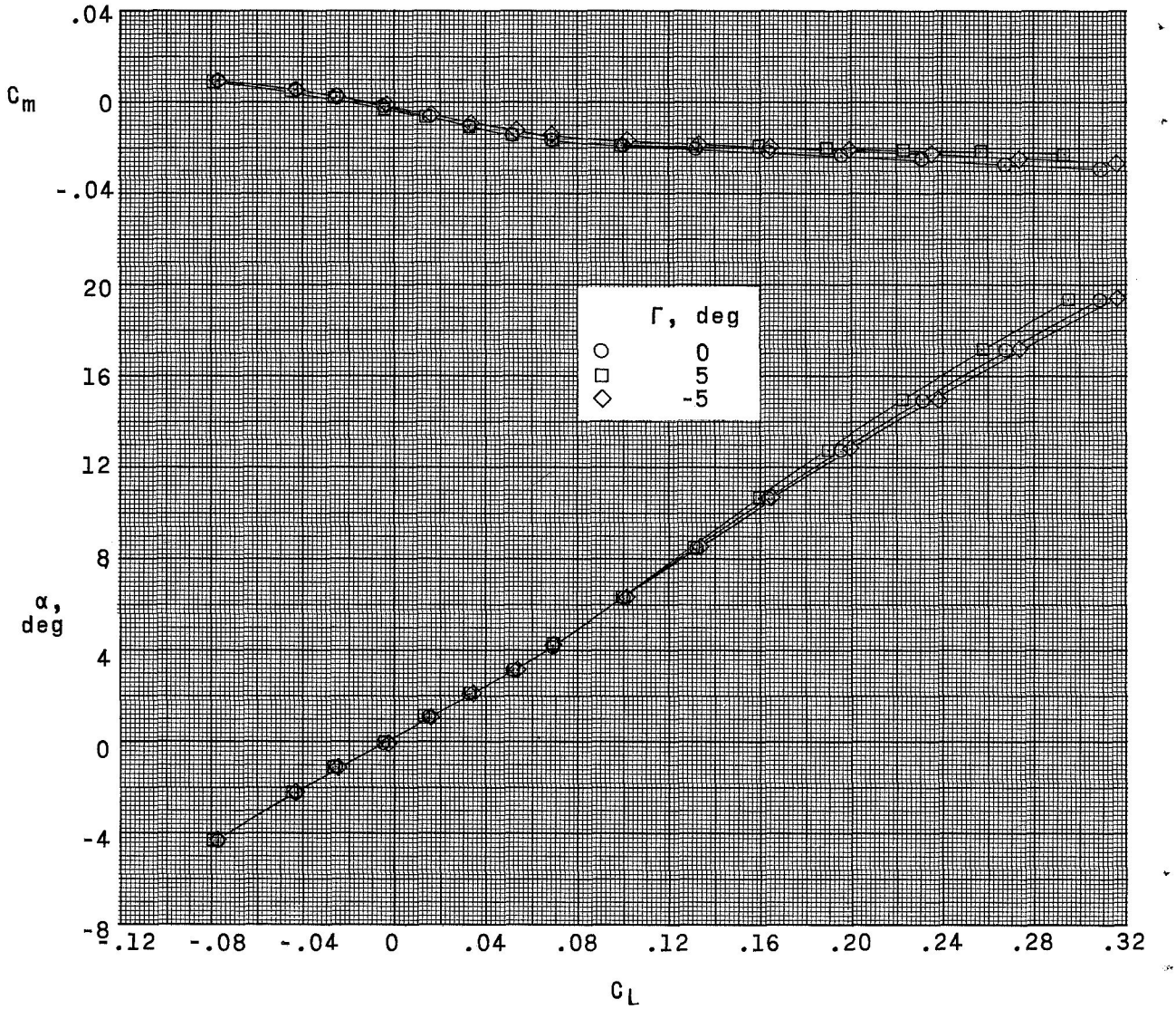
(d) M = 2.96.

Figure 8.- Continued.



(d) Concluded.

Figure 8. Continued.



(e) M = 3.96.

Figure 8.- Continued.

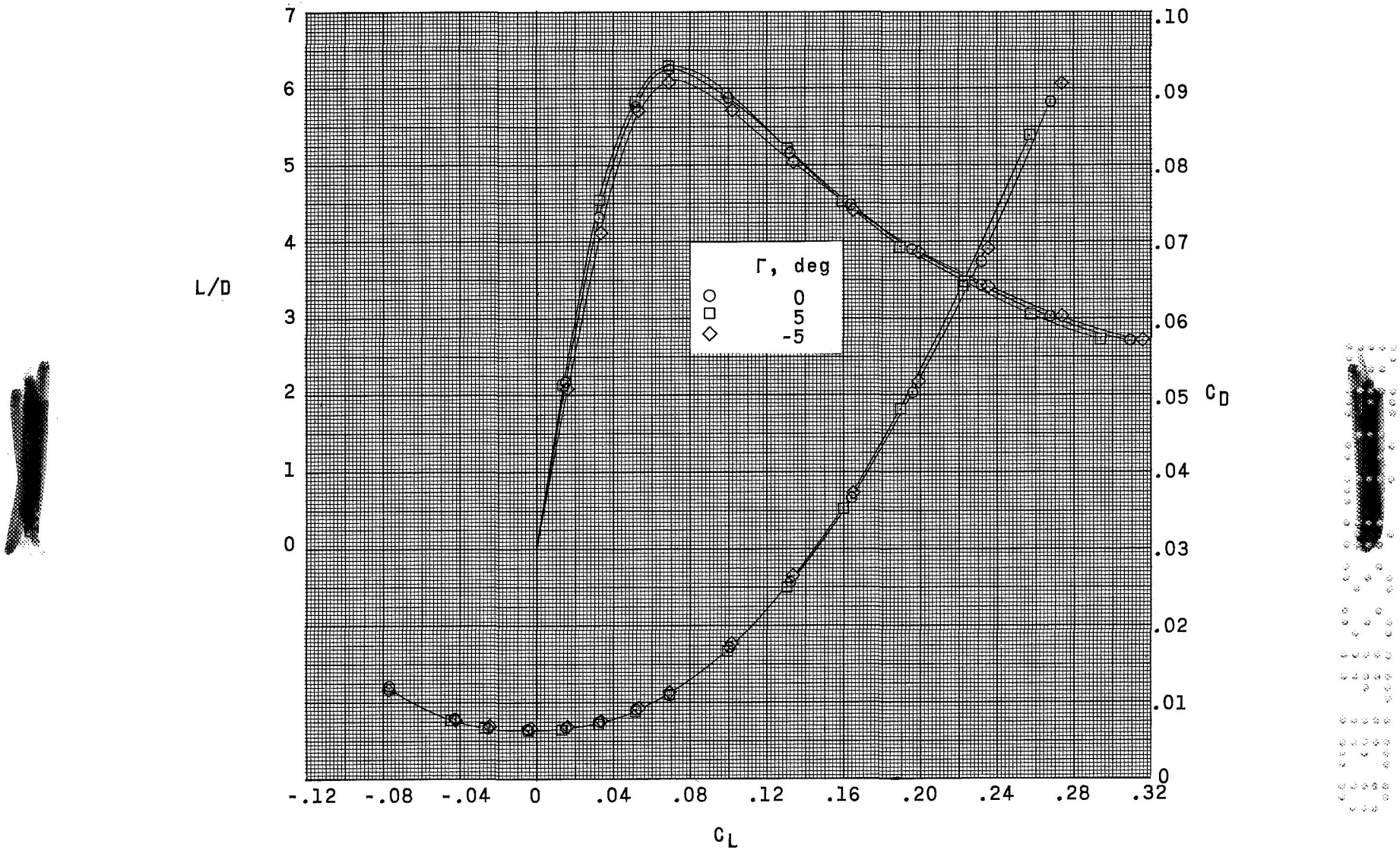


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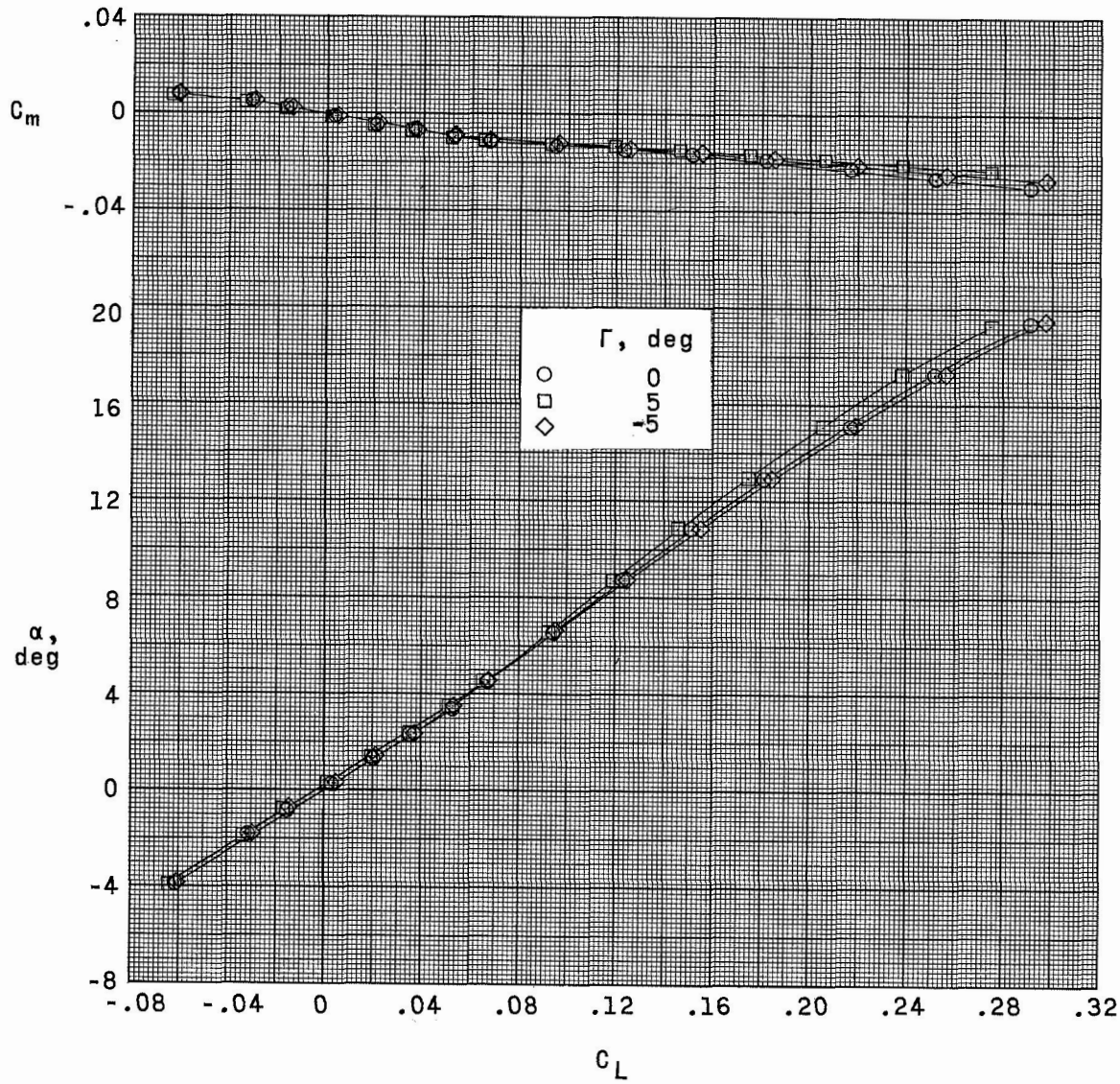
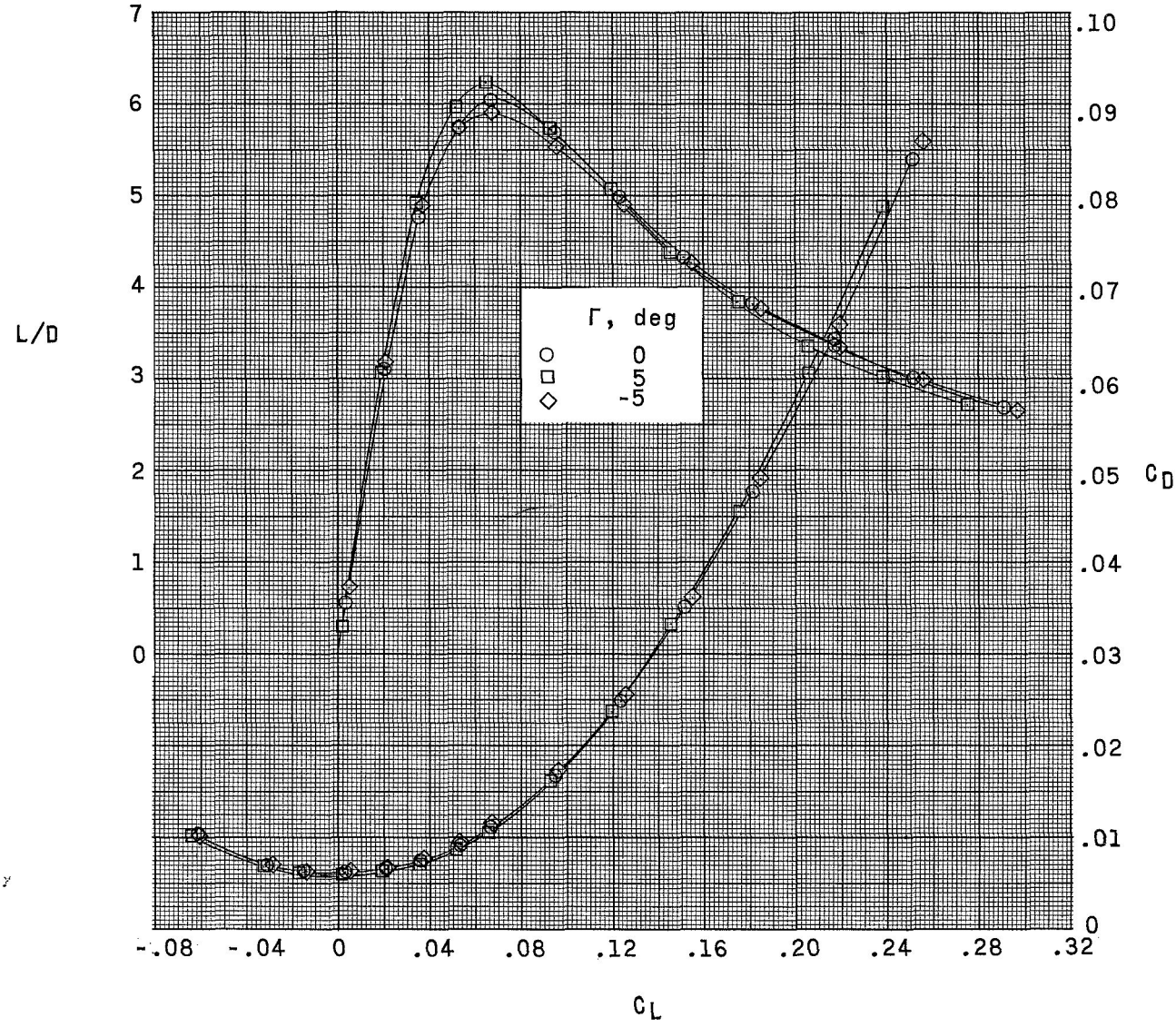
Figure 8.- Continued.



(f) M = 4.65.

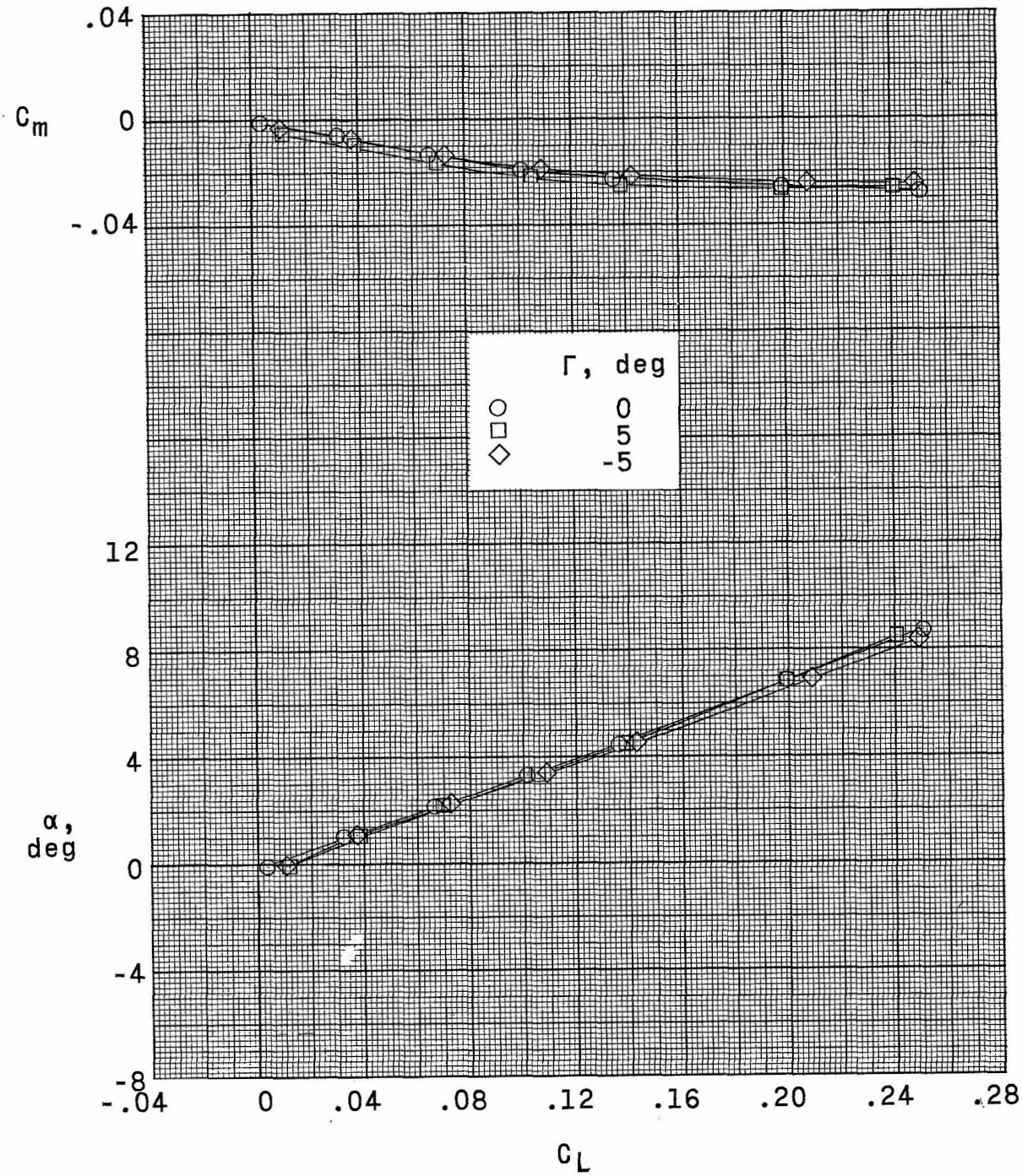
Figure 8.- Continued.

UNCLASSIFIED



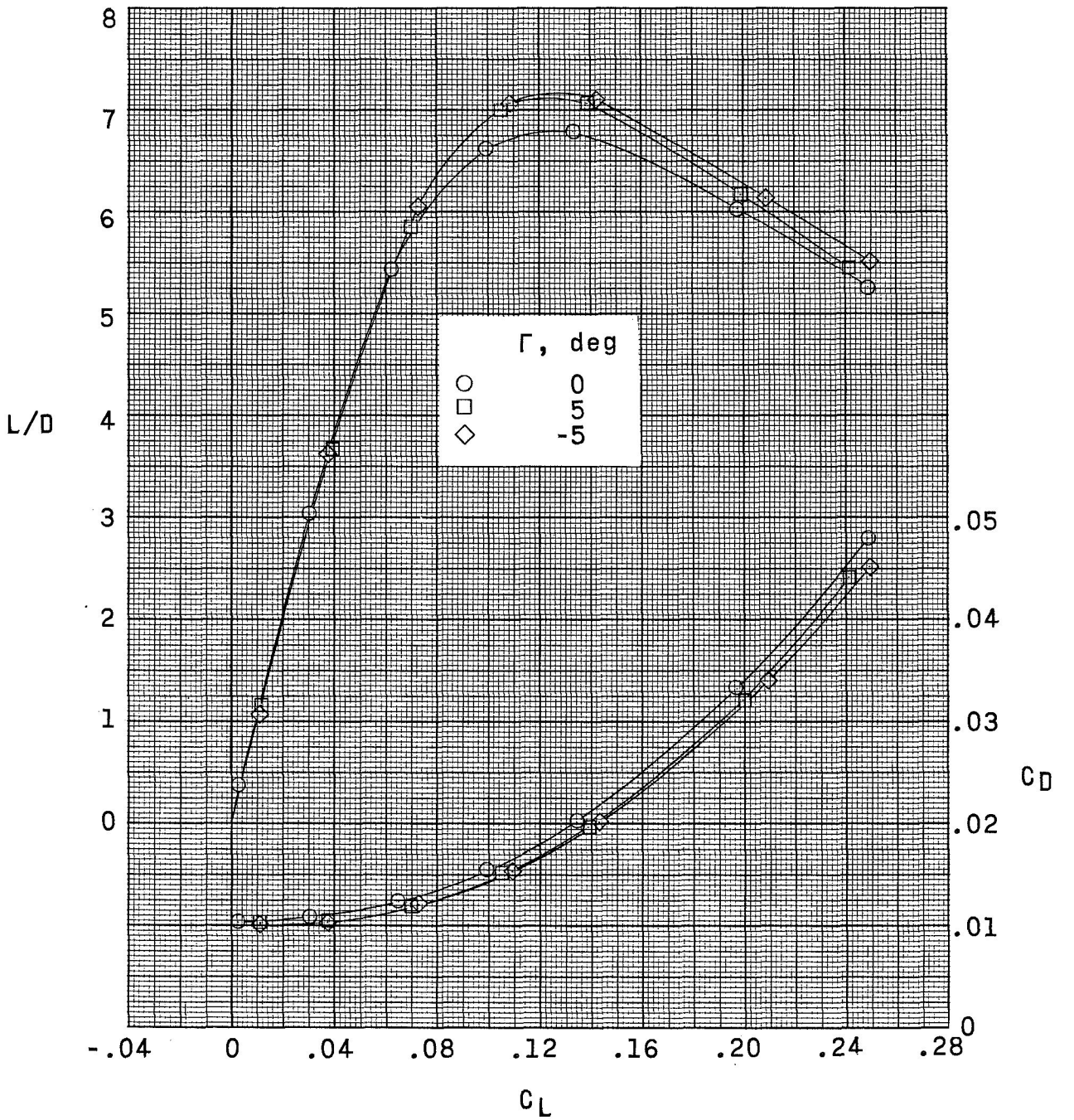
(f) Concluded.

Figure 8.- Concluded.



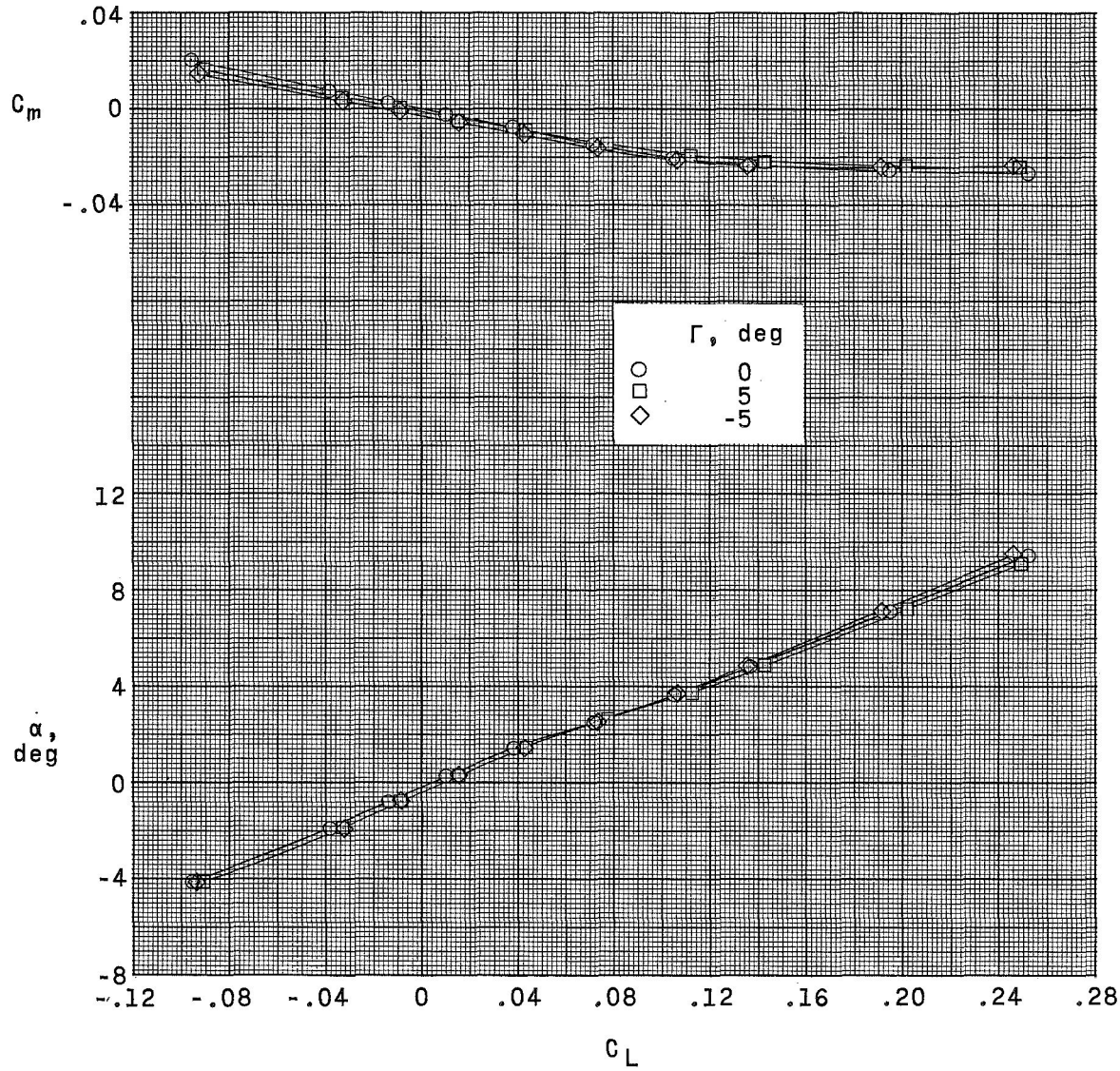
(a) M = 1.60.

Figure 9.- Effect of geometric dihedral on aerodynamic characteristics in pitch for low-wing configuration.



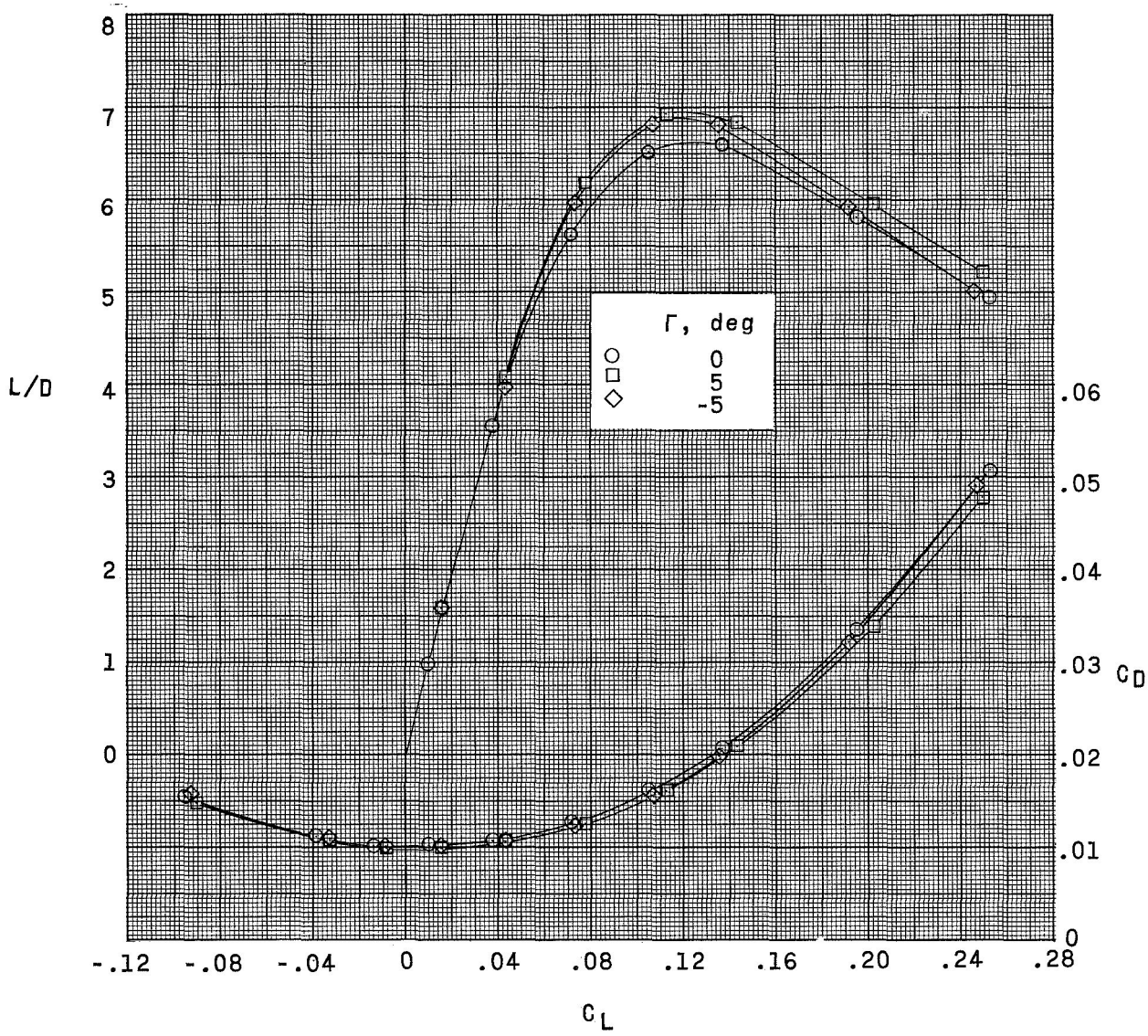
(a) Concluded.

Figure 9.- Continued.



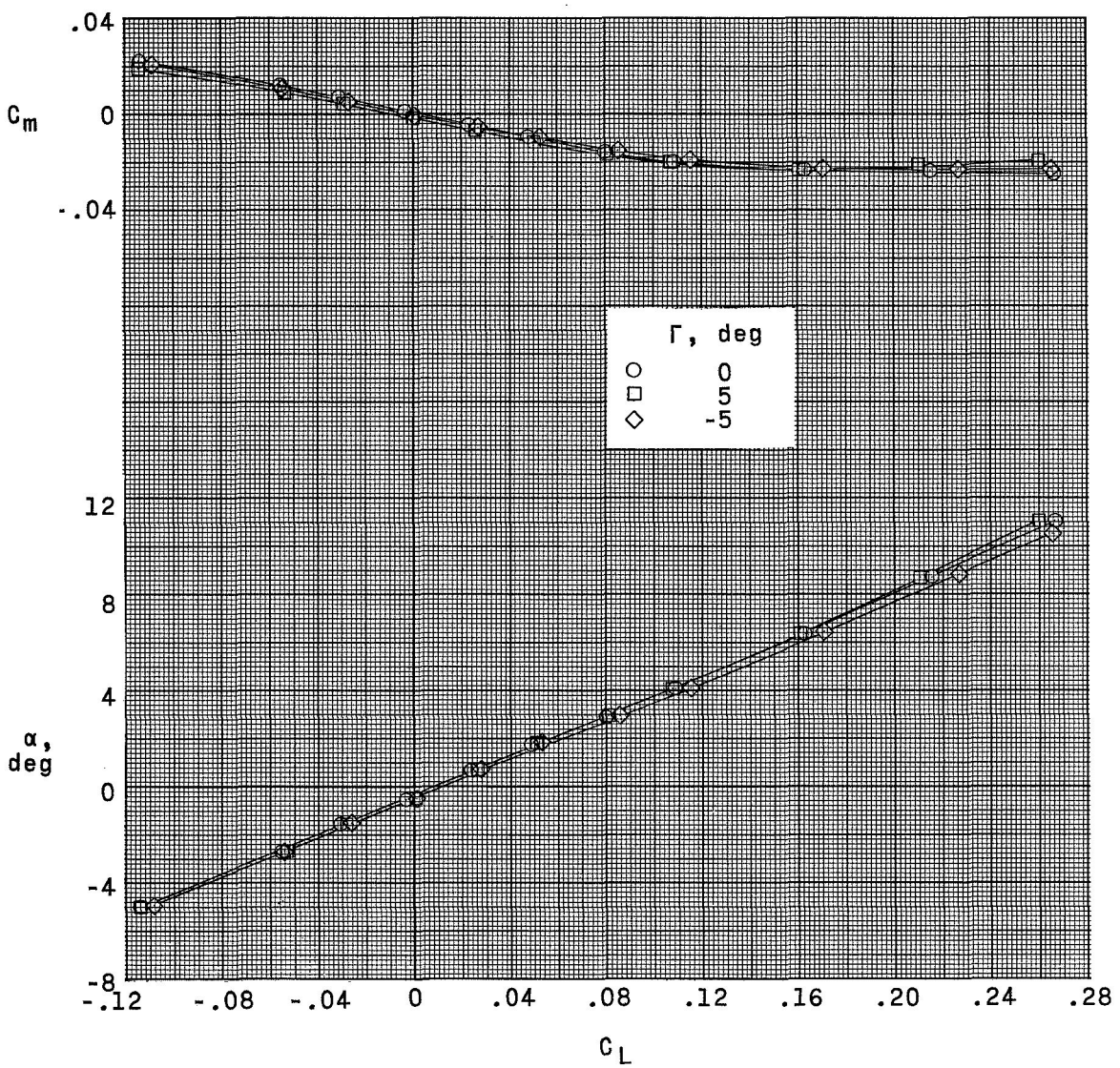
(b) M = 1.90.

Figure 9.- Continued.



(b) Concluded.

Figure 9.- Continued.



(c) M = 2.30

Figure 9.- Continued.

[redacted]CLASSIFIED

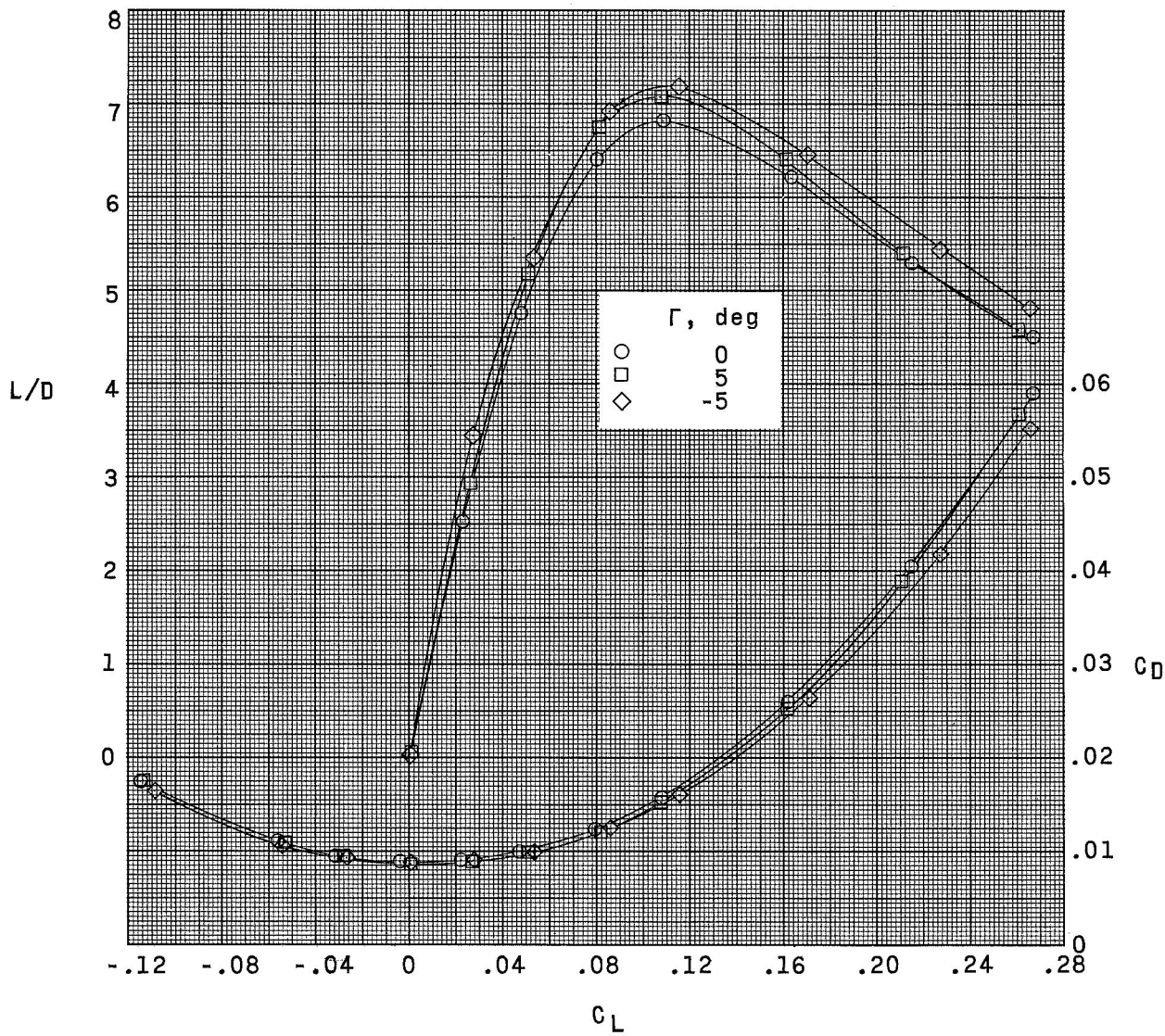


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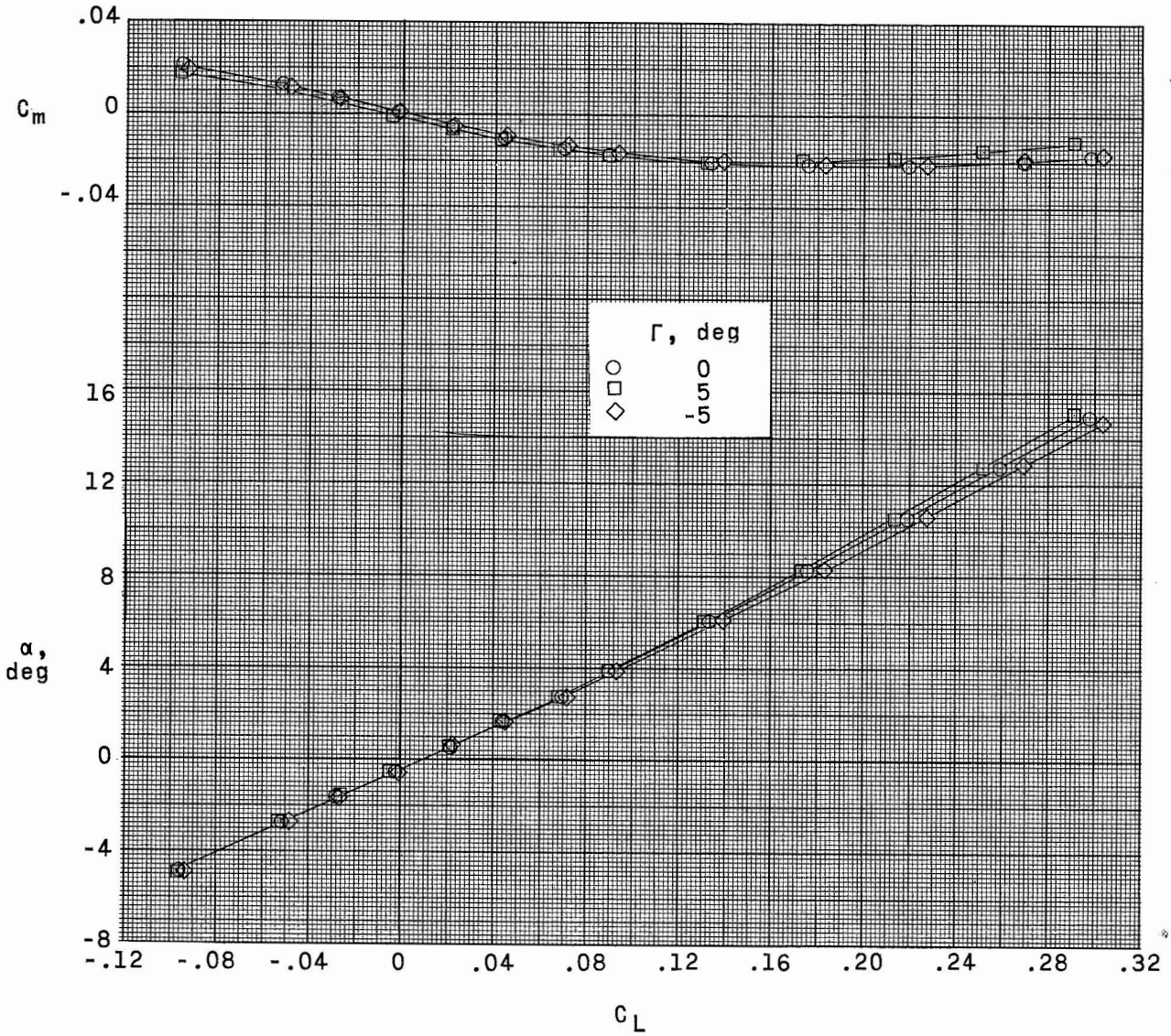
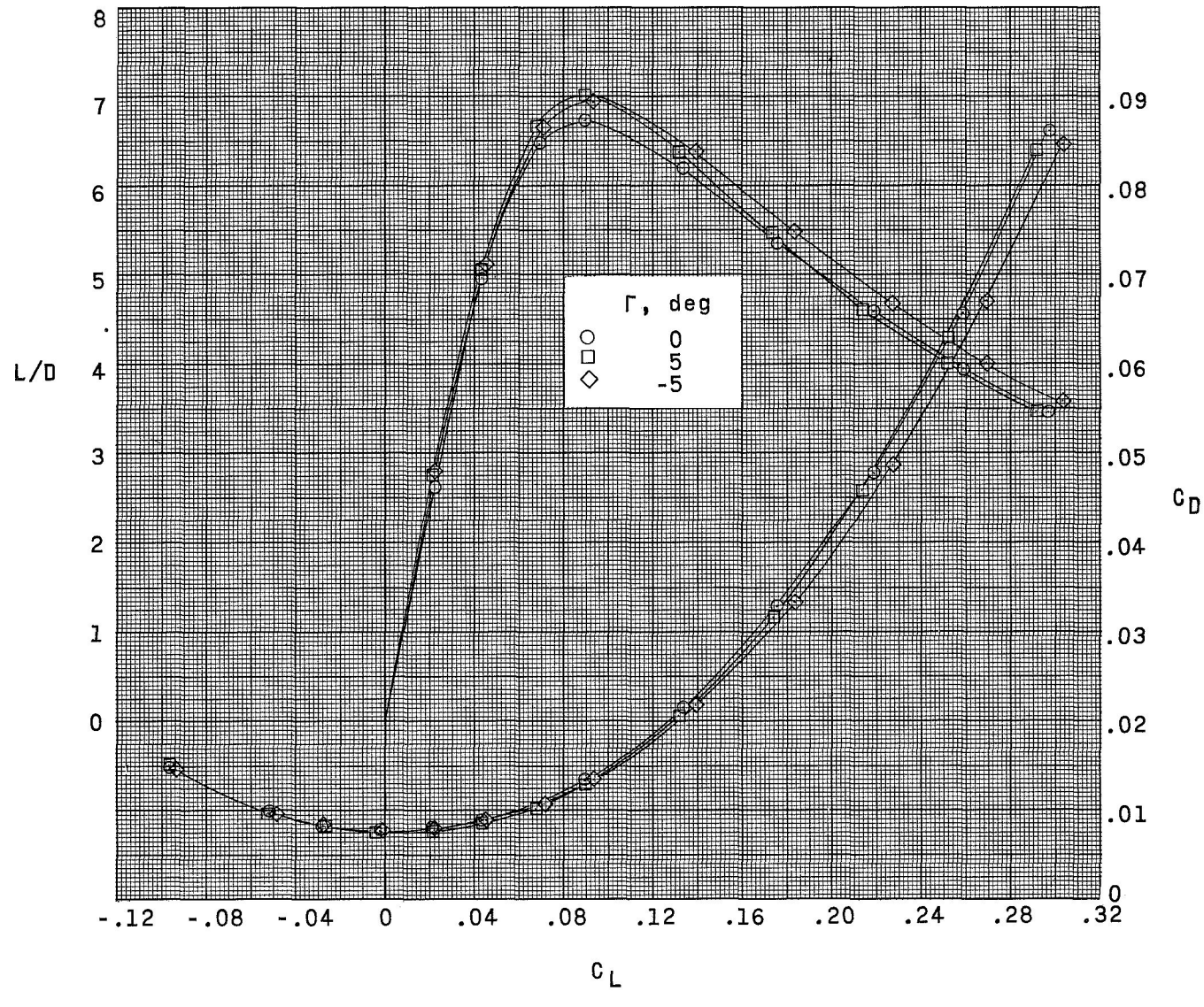
Figure 9.- Continued.



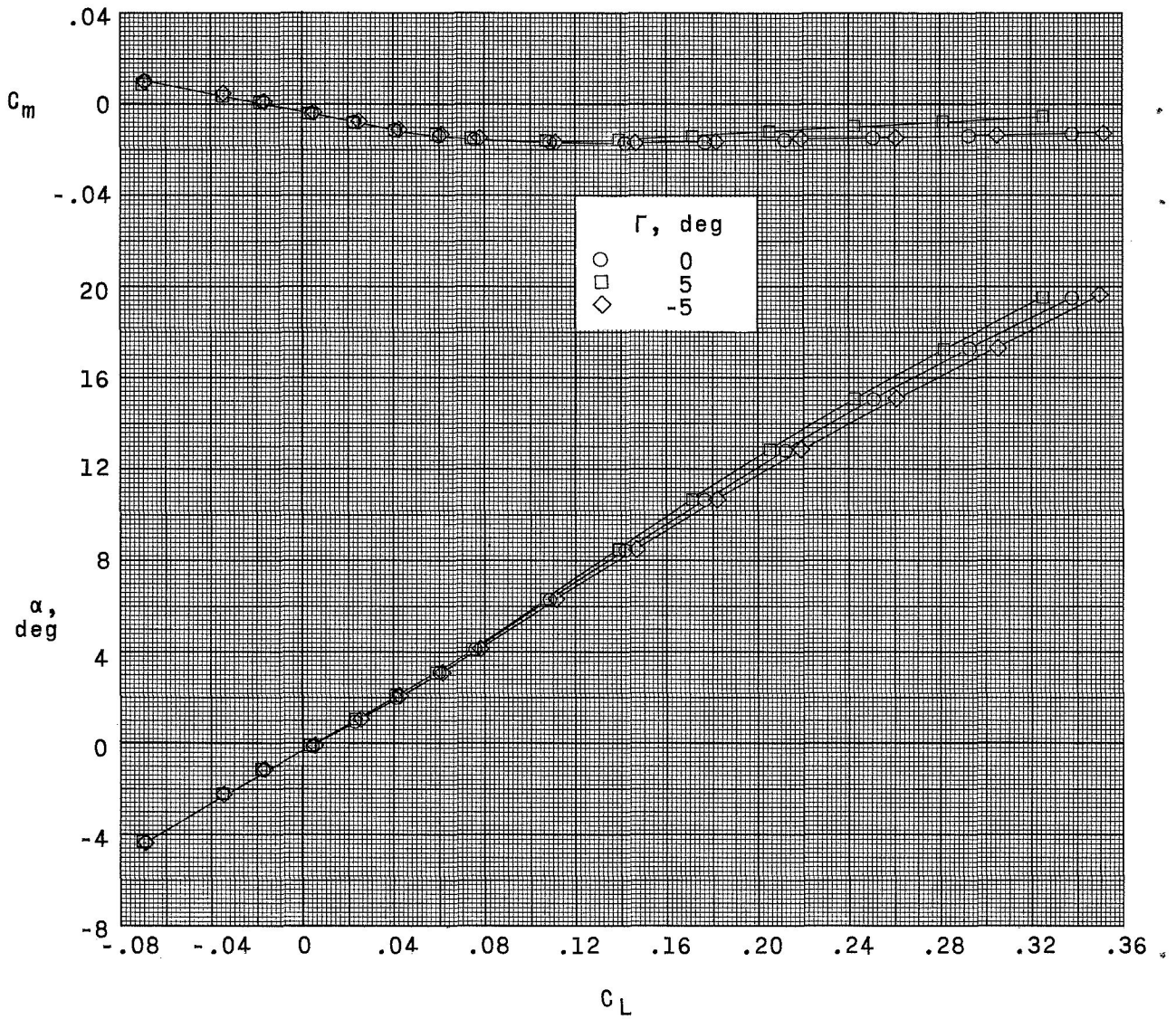
(d) M = 2.96.

Figure 9.- Continued.



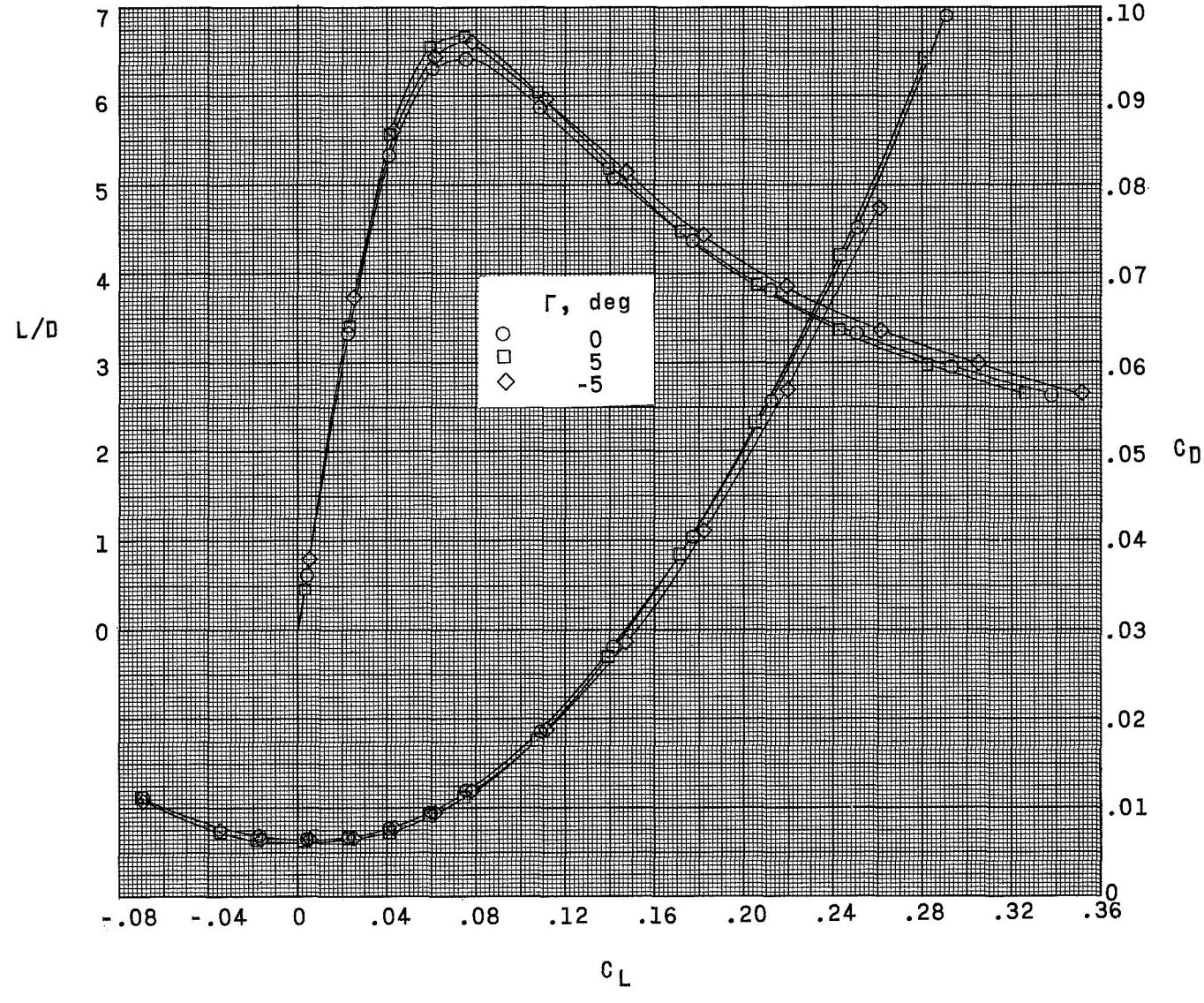
(d) Concluded.

Figure 9.- Continued.



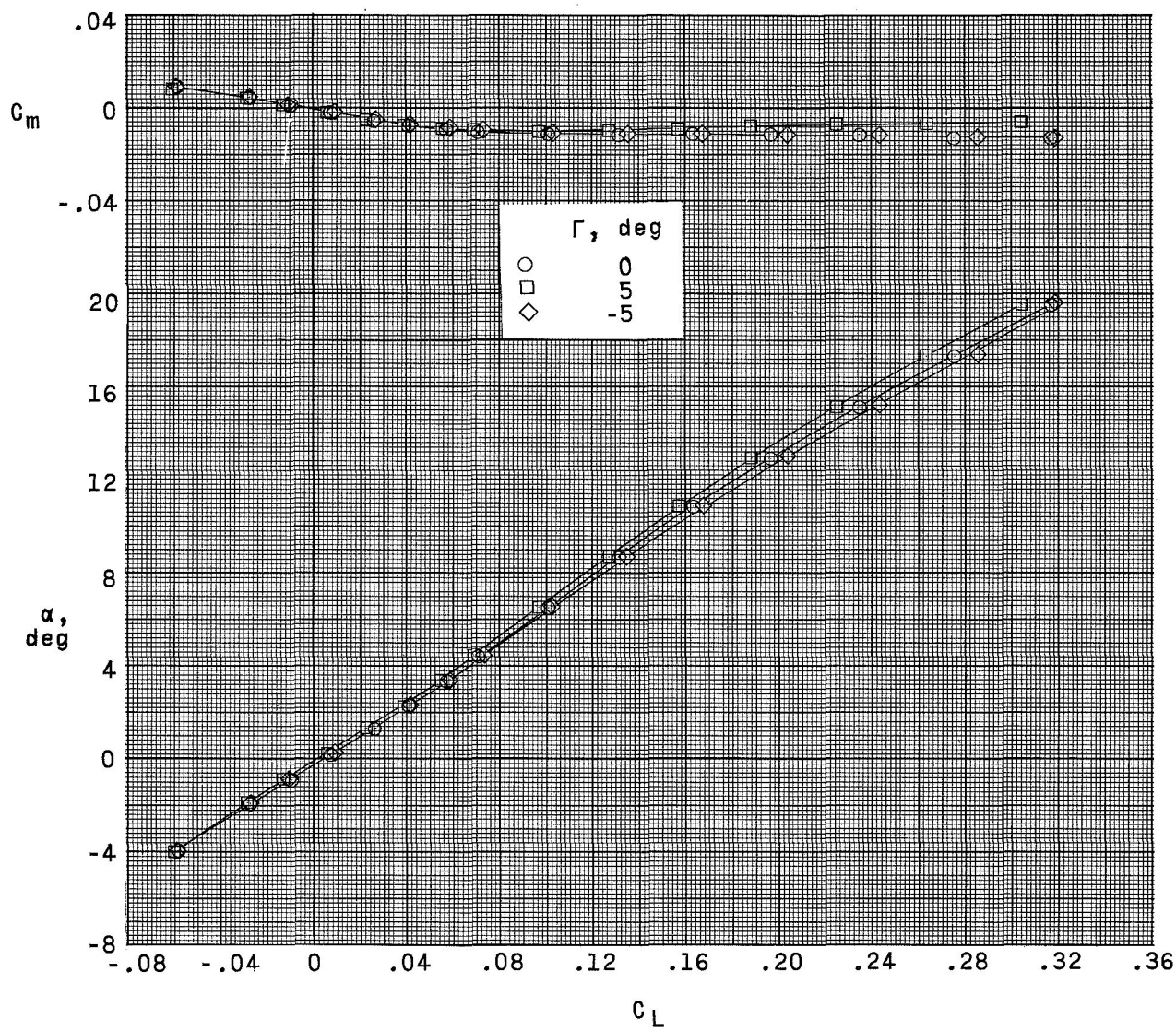
(e) M = 3.96.

Figure 9.- Continued.



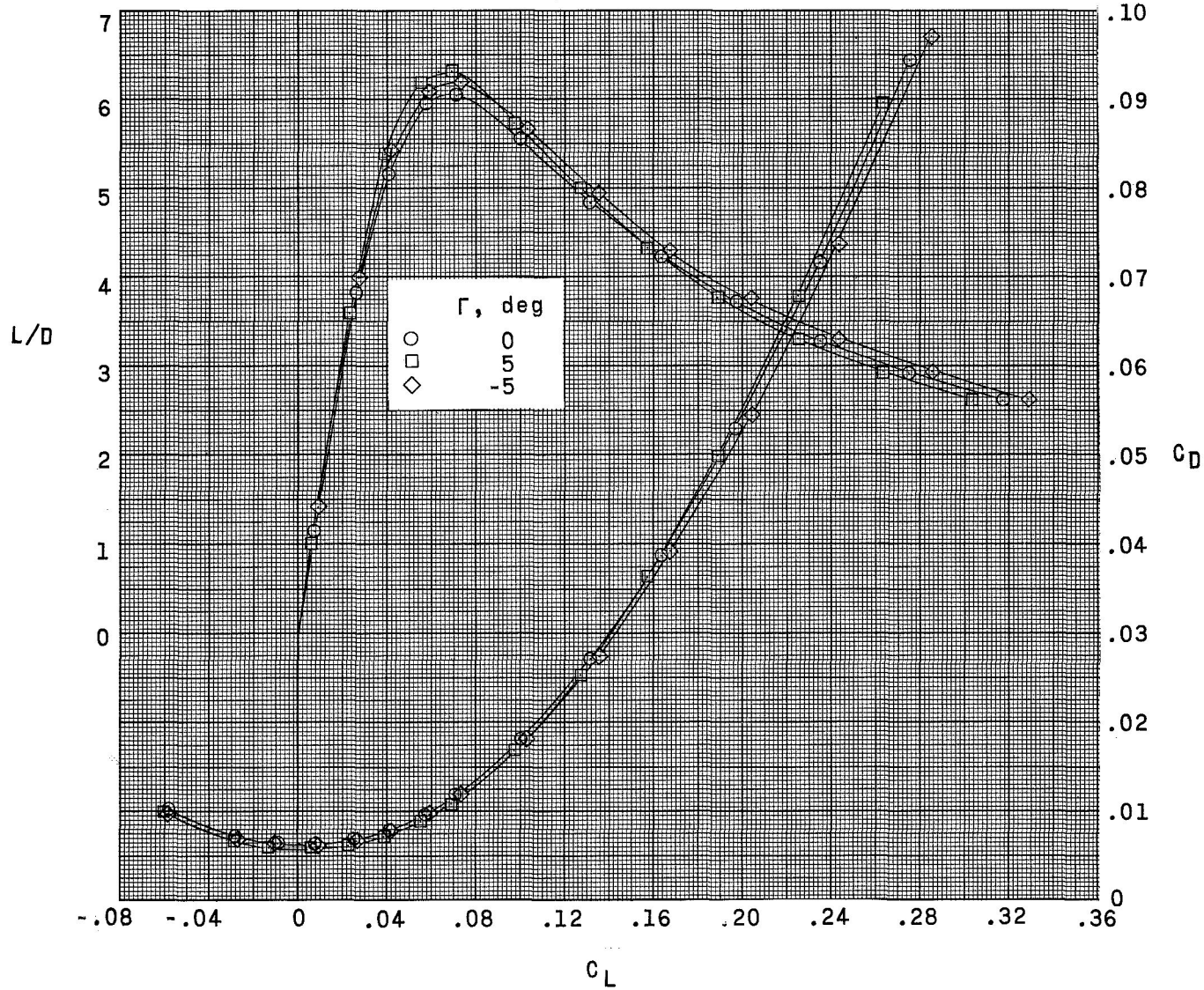
(e) Concluded.

Figure 9.- Continued.



(f) M = 4.63.

Figure 9.- Continued.

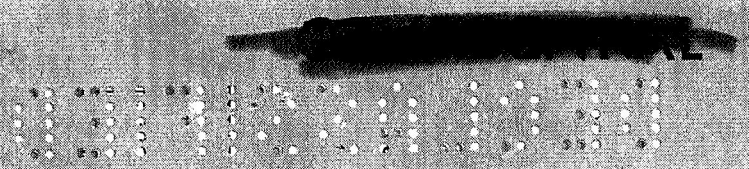


(f) Concluded.

Figure 9.- Concluded.

REDACTED

[illegible]



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—NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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